VOL. XXV. — No. 10. October 1948.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[621 .337]

Individual axle drive.

Mechanical systems used on electric locomotives and railcars, with an indication of the results obtained in service on railways of all kinds,

(Continued)*

by ADOLPHE-M. HUG,

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Chapter IV. (*Continued*)

DRIVING MECHANISM USING SPRINGS (OR RUBBER) WITH TRANSMISSION BY GEARS.

4) In 1937/38, the « Ferrovie Nord Milano » (FNM) in Italy (3 000 V. DC normal gauge) put into service 3 railcars, Nos. 730.01, 730.02 and 730.03, with 4 driving axles, hourly rating 1 100 H.P., max. speed 100 km./h. (62 m.p.h.) (fig. 155) [96]. These cars had a stub hollow shaft. They therefore follow the Brown Boveri flexible drive arrangement, with springs set in the gear wheel body. It has been stated, in error (see « Errata » at the end of the article) that the motive unit of fig. 153 (item 2) was fitted with this mechanism (see text alongside fig. 152). This railcar, No. 787 (new BLS numbering system), has two nose-suspended motors without flexible drive.

(*) See *Bulletin of the International Railway Congress Association*, Nos. of September, October and December 1947, pp. 823, 885 and 999 respectively, Nos. of February, April and July 1948, pp. 73, 227 and 403 respectively.

(96) See « Elettromotrici con commando multiplo sulle linee suburbane delle Ferrovie Nord Milano », U. GARRETTI; proceedings of the XLIV annual meeting of the Italian Electrotechnic Assn. (A.E.I.), Bologna, 1940. — *Rassegna Tecnica* (Tecnomasio Italiano Brown Bovery), Milan, Mar./Apl., 1941, p. 23.

Fig. 155. — Reversible motor unit (motor set plus trailer) of the « Ferrovie Nord Milano » FNM, Series 730, Nos. 01-03, working Milan-Como. The trailer is here leading.

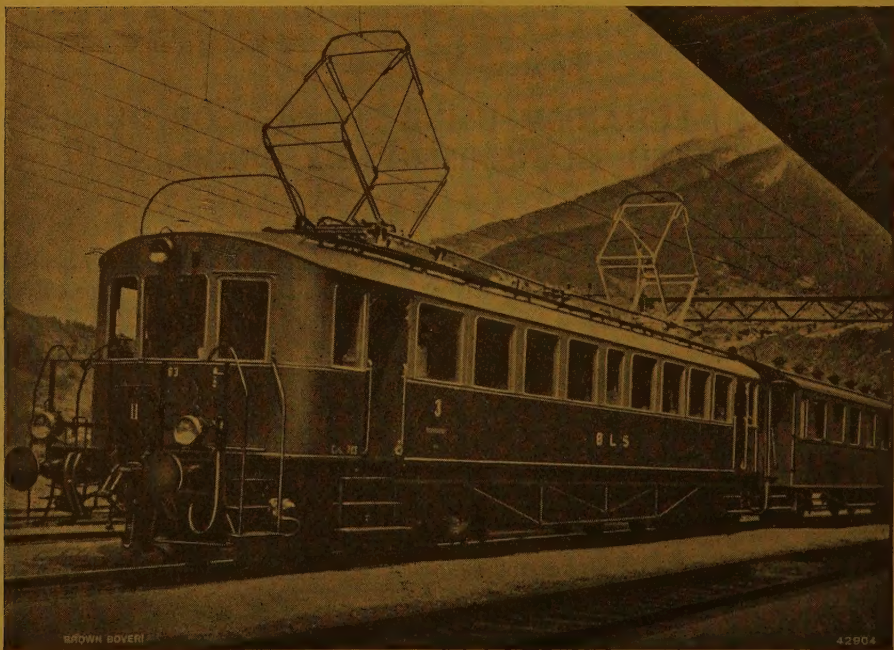

Fig. 156. — Modernised (1910) railcar, type Ce$^4/_4$, No. 783, Lötschberg BLS Ry., Switzerland. [See note correction to note (97).]

5) In 1937, railcar No. 783 ([97]), put into service in 1910 with one driving bogie only, on the Spiez-Frutigen service, type Ce $^4/_4$ of the BLS Lötschberg (Swiss) line, was converted (modernised) and fitted with Brown Boveri drive with springs and oil bath, and stub hollow shaft. The converted car weighs 55 tons (adhesive weight) compared with the previous 57.6 tons of which only 32 tons were adhesive. Hourly rating increased from 450 to 800 H.P., maximum speed in service from 70 to 80 km./h. (43 to 50 m.p.h.). Single phase current, 15 kV. 16 $^2/_3$ cycles (see fig. 156).

6) In 1937/38 a double railcar set (two units on four bogies) was built for the Swiss Federal Railways, CFF-SBB, and shown at the Swiss National Exhibition in Zurich in 1939. This motor set, originally No. 311, then 671, is type RBCFe $^4/_8$. Figs. 157 to 159 show, respectively, the set in service, a dimensioned elevation and plan, and one of the central driving bogies. Fig. 147 shows the mechanism fitted on an axle (stub hollow shaft) ([98]).

Cliché SLM-Winterthur.

Fig. 157. — High speed double car, 4 bogies — 2 driving, type RBCFe $^4/_8$, No. 671, Swiss Federal Railways, double « Red Arrow ».

([97]) See *Brown Boveri Revue*, Baden, March, 1937. Note correction: The BLS Railway informed us, at the time of correcting the proofs, that Car No. 783 had, and retained after conversion, nose-suspended motors without flexible drive. This is therefore a mistake, as also are the remarks concerning fig. 153.

([98]) See *Revue Polytechnique Suisse, SBZ*, Zurich, 15/7/39, pp. 27-32, 12 fig. — *Bulletin CFF*, Berne, No. 12, 1940. — See remarks on figs. 146-150, then the previous note regarding fig. 134 and following. — Regarding the « Red Arrow » double set No. 301, Re $^4/_8$, now 651 (RBe $^4/_8$), see *Bulletin des CFF*, Berne, No. 7/1939, pp. 108-110. — See also, regarding the body structure, *Bulletin Technique SLM*, Winterthur, Dec. 1942, pp. 11-17.

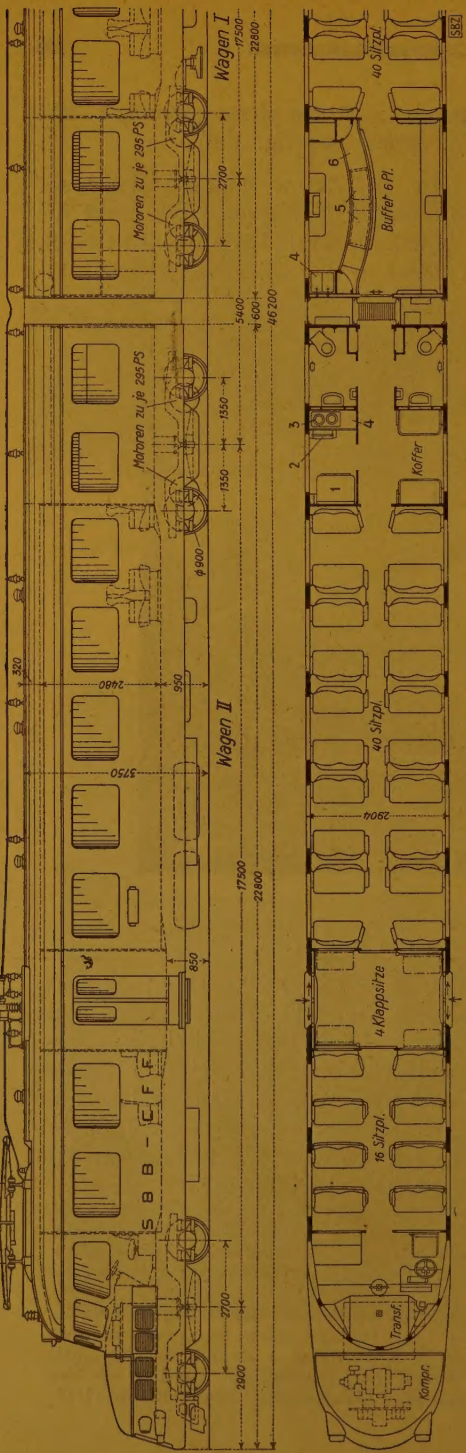

Fig. 158. — Dimensioned sketch in plan and elevation of the double car shown in fig. 157. Cliché « Revue Polytechnique Suisse SBZ ».

This set was built for an operating speed of 150 km./h. (93 m.p.h.) and is approximately 1 200 H.P. (single phase, 15 kV., 16 $^2/_3$ cycles).

7) Also in 1937/38, 3 railcar luggage vans, type RFe $^4/_4$, series 601, Swiss Federal Railways, were put into service for hauling light sets. Fig. 160 shows one of these van railcars which was built for a maximum operating speed of 125 km./h. (78 m.p.h.) with an hourly rating of 1 160 H.P. [100]. These cars were built for the haulage of light express trains, but owing to increasing operating demands, they became too lightly powered, and were transferred, one to the SOB (South-eastern (Swiss) Railway) and two to the BT (Bodensee-Toggenburgbahn) Railway. In their place, the CFF placed in service the light locomotives, Re $^4/_4$, series 401, described later (under item 19). Fig. 161 shows one of the same van railcars RFe $^4/_4$, hauling a light train, fig. 162 a driving bogie and fig. 163 a sketch of the construction and suspension of these bogies (built by SLM-Winterthur).

8) In 1938, the Swiss Federal Railways put into service 2 Diesel-electric locomotives, B_0-B_0 type, class Am $^4/_4$, series 1001, DC motors, maximum operating speed 110 km./h. (68 m.p.h.), hourly rating 860 H.P. [101]. Figs. 164 and 165 show, respectively, the engine in service and a driving bogie. The driving mecha-

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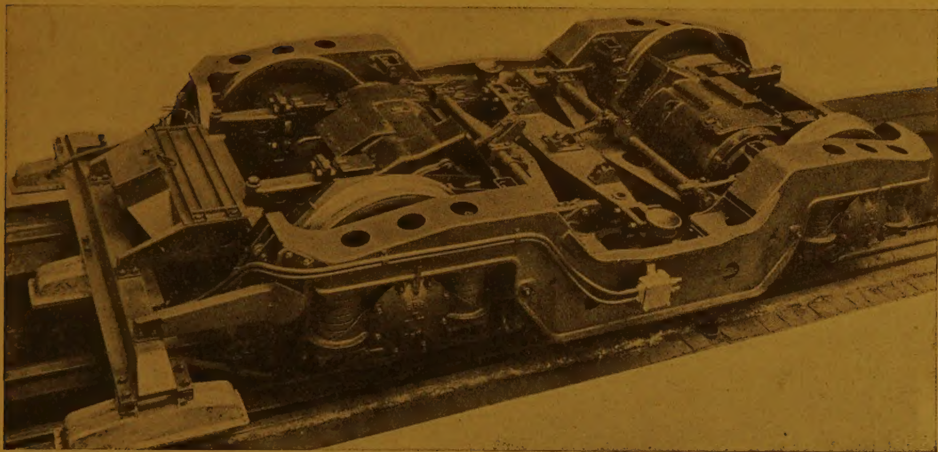
[100] See *Bulletin des CFF*, Berne, Nos. 3 and 7/1940, F. STEINER and W. MÜLLER, CFF; regarding the results of the trials, Nos. 11 and 12/1940, with diagrams and tables. — *Bulletin Technique SLM*, Winterthur, Nov. 1941, pp. 3-6; *Revue Brown-Boveri*, Baden, Switzerland, June/July, 1946 (German) pp. 135-136.

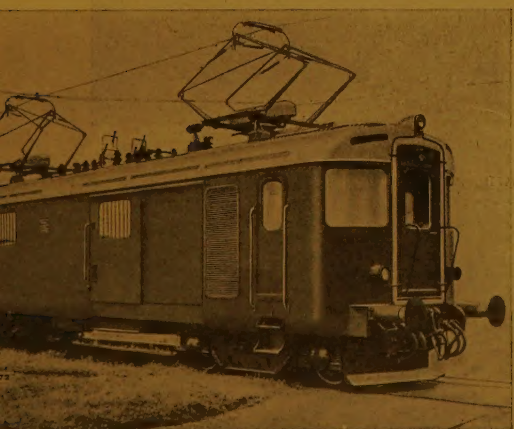
[101] See *Bulletin des CFF*, Berne, No. 6/1939, pp. 90-92; *Revue Brown Boveri*, Baden, May, 1940, pp. 99-108, A.-E. MÜLLER, and June, 1940, pp. 123-127.



Cliché « Revue Polytechnique Suisse SBZ ».

Fig. 159. — A driving bogie of the double car shown in figs. 157 and 158 (see fig. 147) provided (left — see right on fig. 158) with Signum-Integra safety magnets.

nism is shown in fig. 150. The locomotives have been in continuous service for 10 years and are giving complete satisfaction. Mechanical parts [as for types noted under 1), 6) and 7)] were built by the SLM Co., Wintherthur, Diesel motors were by Sulzer Bros. and the electrical equipment by Brown Boveri. The drive has a stub hollow shaft.

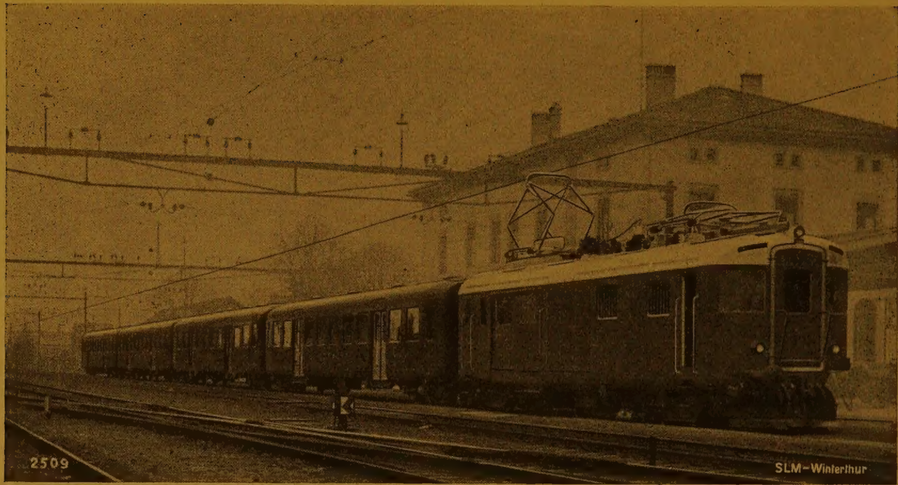


Cliché Sécheron.

. 160. — Motor van RFe $^4/_4$, Series 601, Swiss ederal Railways, 1937, since transferred to the wiss S.O.B. and B.T.

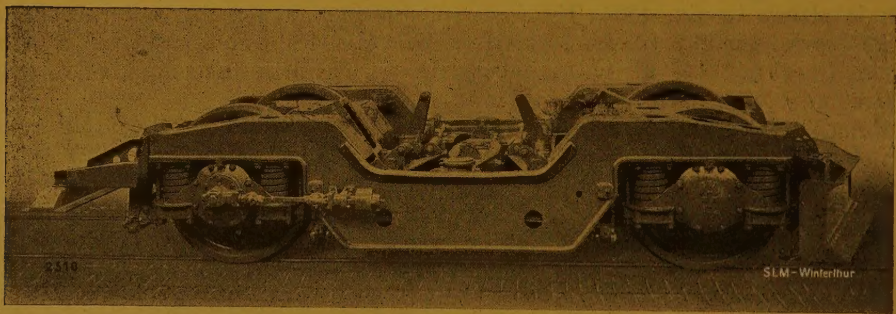
9) In 1938/39, the Swiss Rhaetian Railway (Rhätische Bahn) Rh.B. (1 m. gauge, single phase, 11 kV., 16 $^2/_3$ cycles), put into service 4 railcars fitted with the same arrangement (stub hollow shaft). These cars are type BCe $^4/_4$, series 501 (fig. 166) ([102]). In view of the nature of the system, grades of 35 and 45 per mille (even 70 per mille on the Ch.-A. & BB lines) and the numerous curves on the Grisons and Engadine lines, the maximum speed is limited to 65 km./h. (40 m.p.h.), hourly rating is 620 H.P. These railcars work with trailers of similar type.

([102]) See *Economie et Technique des Transports*, Lucerne, 68/69, 1947, pp. 32-33 (article of J. BERTSCHMANN, Rh.B.). — *Bulletin Oerlikon*, Zurich, No. 237, pp. 1481-1484, M. PHILLIPIN; see also pamphlet published for International Railway Congress at Lucerne, 1947, p. 11.



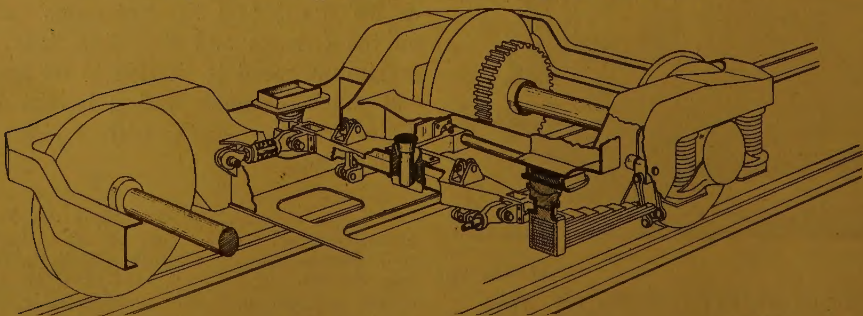
Cliché SLM-Winterthur.

Fig. 161. — Swiss motor van as for text of fig. 160 hauling a light CFF train.



Cliché SLM-Winterthur.

Fig. 162. — Bogie of car shown in figs. 160 and 161.



Cliché SLM-Winterthur.

Fig. 163.— Sketch showing arrangement of bogie in fig. 162.

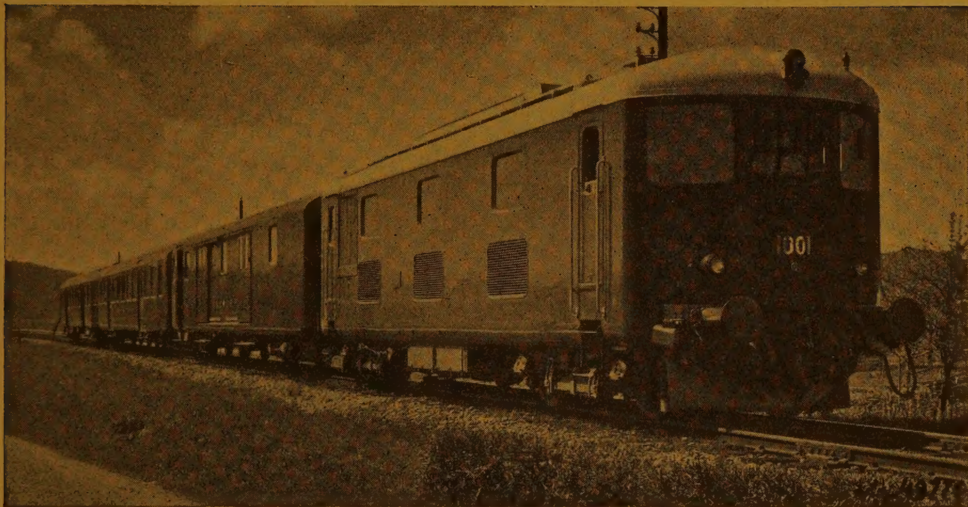


Photo BBC.

Fig. 164. — Diesel-electric locomotive, series 1001, type Am $^{4}/_{4}$, hauling a light train on the Swiss Federal system.

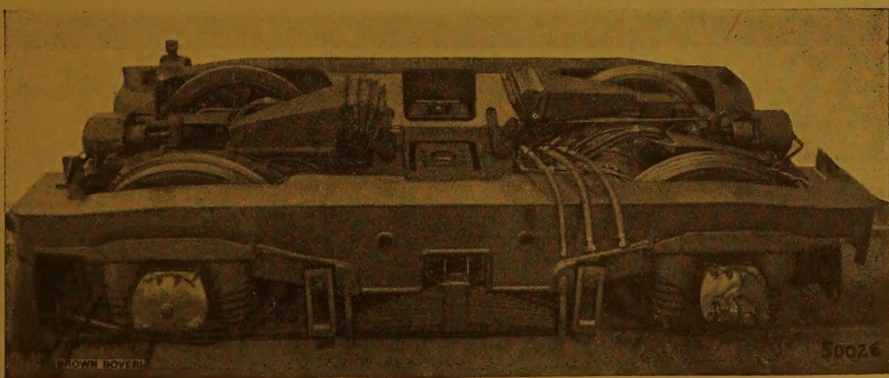


Fig. 165. — Driving bogie of locomotive in fig. 164.

10) In 1935, the Czechoslovakian State Railways « Ceskoslovenske Státni Drahy » CSD, put into service two Diesel-electric railcars « Slovak Arrow », 4 axles arranged 1A-A1, series M.290.0, Nos. 001 and 002, with this arrangement (one driving axle per bogie, stub hollow shaft). Hourly rating 330 H.P., maxi-

mum operating speed 130 to 140 km./h. (80 to 87 m.p.h.) ([103]). See figs. 167-169.

11) In 1939/40, the Swiss Federal Railways put into service the first locomotive to be provided with a combustion turbine as the primary power unit; DC motors. This was a locomotive, type 1A-B_0-A1, class Am $^4/_6$, No. 1101, hourly rating about 1 700 H.P., maximum operating speed 110 km./h. (68 m.p.h.) ([104]). Figs. 170-172 show, respectively, a dimensioned sketch, complete, in elevation; the engine with a train, in service, and one of the combined bogies. The two central driving axles are mounted on the body under-

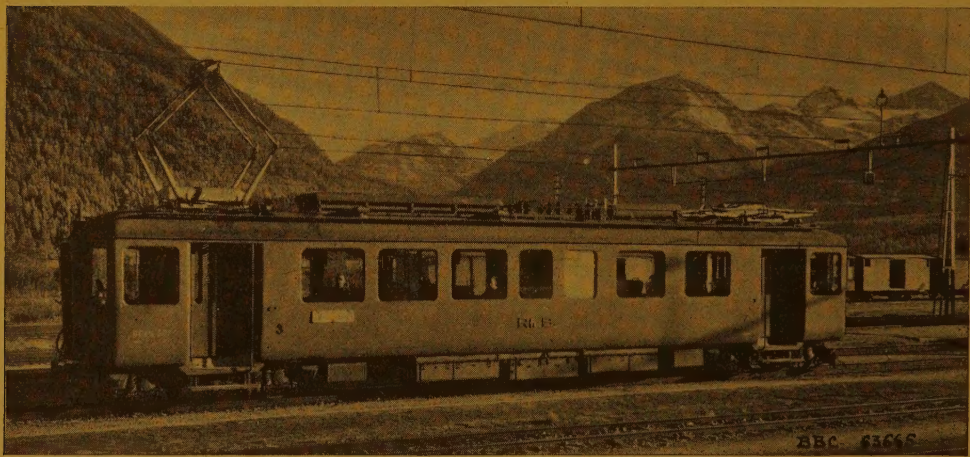


Fig. 166. — Electric railcar, type BCe $^4/_4$, series 501, Rhätische Bahn (Rh.B.) in Switzerland, for mountain lines.

([103]) See : *Zeleznici revue*, Prague, No. 11, 1936, p. 165, « Slovenská Strela » (Slovak Arrow). — *Zprávi ver. sluzbi techn.*, Prague, 10/5/36 (Vol. XVIII, No. 14, pp. 331-332), « Nové rychlé motorové vozy r. M290.0 (New high speed motor coaches, series M290.0) », J. LEINER. — *Der Monat*, Nos. 7/8, 1937, « Elektromechanische Übersetzung der Schnellzugmotorwagen Slovenská Strela », SOUSEDIK. — *Elektrotechnicky Obzor*, Prague, Vol. 26, 1937, Nos. 16 and 21, Dr. J. BILEK, 17 fig. — *I.R.C. Bulletin*, Vol. XIX, 1937, No. 1, pp. 239-248, P. KOLLER. — *Economie et Technique des Transports*, Lucerne, No. 1-2, 1937, P. KOLLER. — *Verkehrstechnik*, Berlin, No. 12, 1938, pp. 281-283, « Schienentriebwagen der Tchechoslow. Staatsbahnen », A. BIRK. — *Railway Gazette* (Diesel Railway Traction), London, 3/7/38, pp. 93-95, « Thirteen Years of Diesel Traction in Czechoslovakia », G. HARCAVI. — *Motorzugförderung auf Schienen*, Vienna, J. Springer, 1938, « Das system Sousedik », O. JUDTMANN, 1 fig., 1 diagr. — *Automobil a zeleznice*, Prague, 1938, pp. 49-57, 4 diagr., 2 tables, P. KOLLER; then pp. 71-78, 5 diagr., O. JENISTA; *Strojnicky Obzor*, 5/12/37, Vol. XVII, No. 23, pp. 502-513, K. VETTER. — *Railway Gazette*, Diesel Railway Traction, No. 175, p. 169, « The Slovak Arrow Railcars. — *La Route du Rail*, Paris, 1947, XI, Vol. 3, No. 21, p. 14, 4 figs., O. KOSTELECKY.

([104]) See « The first gas-turbine locomotive », *SBB-Nachrichtenblatt*, Berne, No. 10, Oct. 1941, pp. 165-167. — *Revue Brown Boveri*, Baden, May 1942, pp. 116-126, and Oct./Nov. 1945, pp. 353-360. — *Bulletin Technique SLM*, Winterthur, Dec. 1942, pp. 22-24, etc.

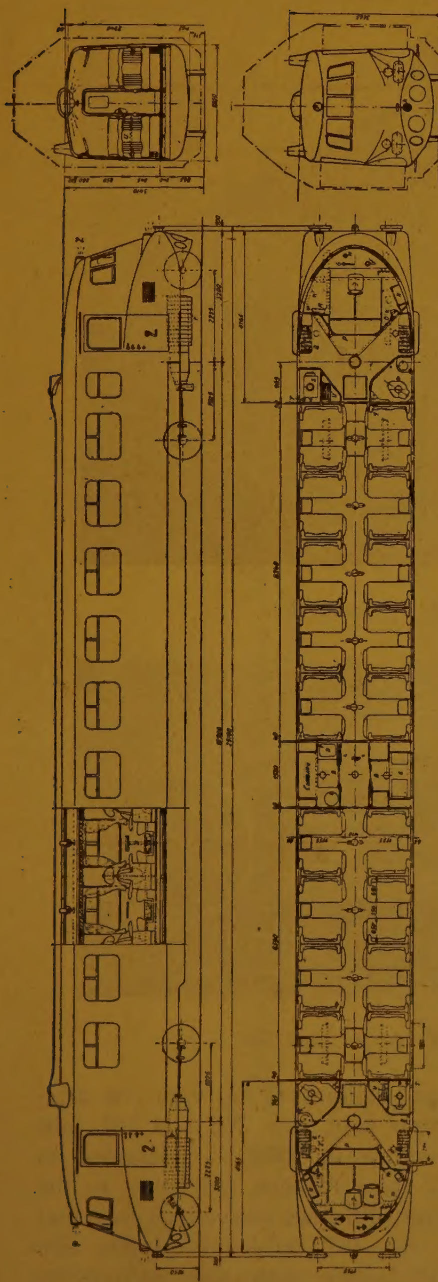


Fig. 167. — Dimensioned plan, elevation, cross section and front view of diesel-electric express railcar « Slovak Arrow ». Czechoslovakian State Railways, C.S.D.

frame. The gas turbine is of 2 200 H.P. at a speed of 5 200 r.p.m. This locomotive has maintained train services over long periods on various lines of the SNCF system.

12) In 1945-46 ([105]), the Norwegian State Railway, NSB (Norges Statsbaner) put into service, 4 express railcars with 4 driving axles (bogies) for maximum speeds of 120 km./h. (75 m.p.h.), hourly rating about 1 000 H.P. These were series CFmeo, type 106, Nos. 18535-18538, for single-phase current 15 kV., 16 $^2/_3$ cycles (fig. 173). These railcars were built in Norway, by the Skabo Jernbanevognfabrik for mechanical parts and by Norsk Elektrisk and Brown Boveri for electrical equipment.

13) We may mention here, various railcars of the BLS :

a) the six railcars of 1929, *converted* in 1941/42, of the Bernese Alps, Berne-Lötschberg-Simplon, BLS, and Berne-Neuchâtel, BN, type Fe $^4/_5$, Nos. 791 to 795 (originally numbered 721 to 725, former designation CFe $^4/_5$) are of the BN, No. 796 of the BLS. These railcars, one bogie of which was provided with a carrying axle situated between the two driving axles (owing to the load distribution) were originally fitted with nose-suspended motors. The cars were intended as passenger vehicles, but since their conversion they have been used as

([105]) These cars are mentioned here because they had already been ordered, in 1940/41 (under the German occupation) ; in order of their placing in service they should come, instead of under 12), under 17) and before 18). In the Appendix will be noted the relevant publications, as well as other applications (locomotives, various mechanisms) of the Norwegian NSB.

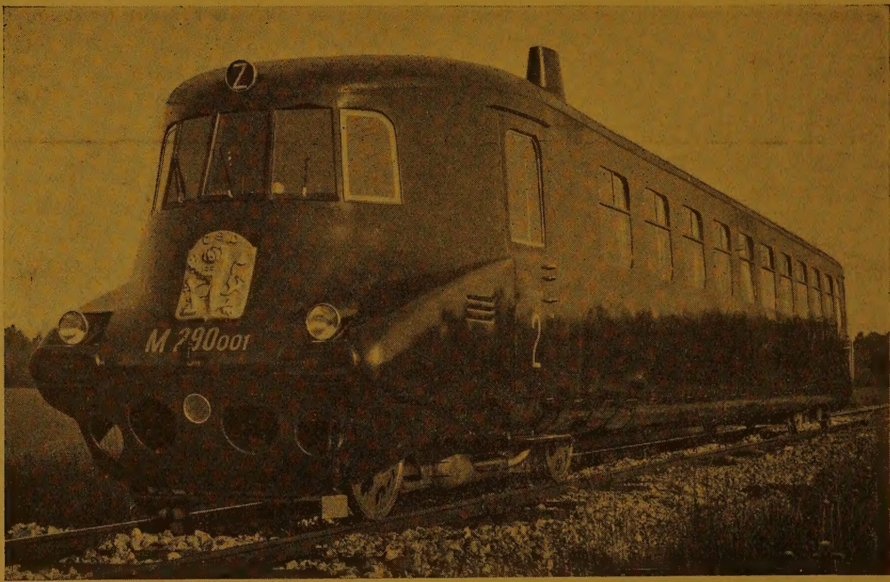


Fig. 168. — Railcar shown in fig. 167, in service.

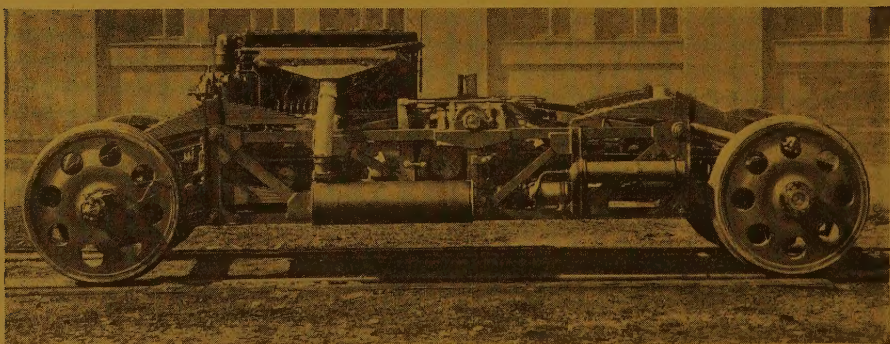


Fig. 169. — Bogie of car shown in figs. 167 and 168.

luggage vans; the springing has been modernised on car No. 791 for trial purposes.

In addition, the following railcars or railcar sets have been *converted* to the same type of flexible transmission of the drive from the motor :

b) two railcars, Ce $^2/_4$, with one driving bogie only, Nos. 702 and 704 (put into service in 1938 — converted in 1946); these railcars, belonging to the SEZ and GBS lines respectively [see text under fig. 133, left-hand column, also note (84)] have, since their conversion,

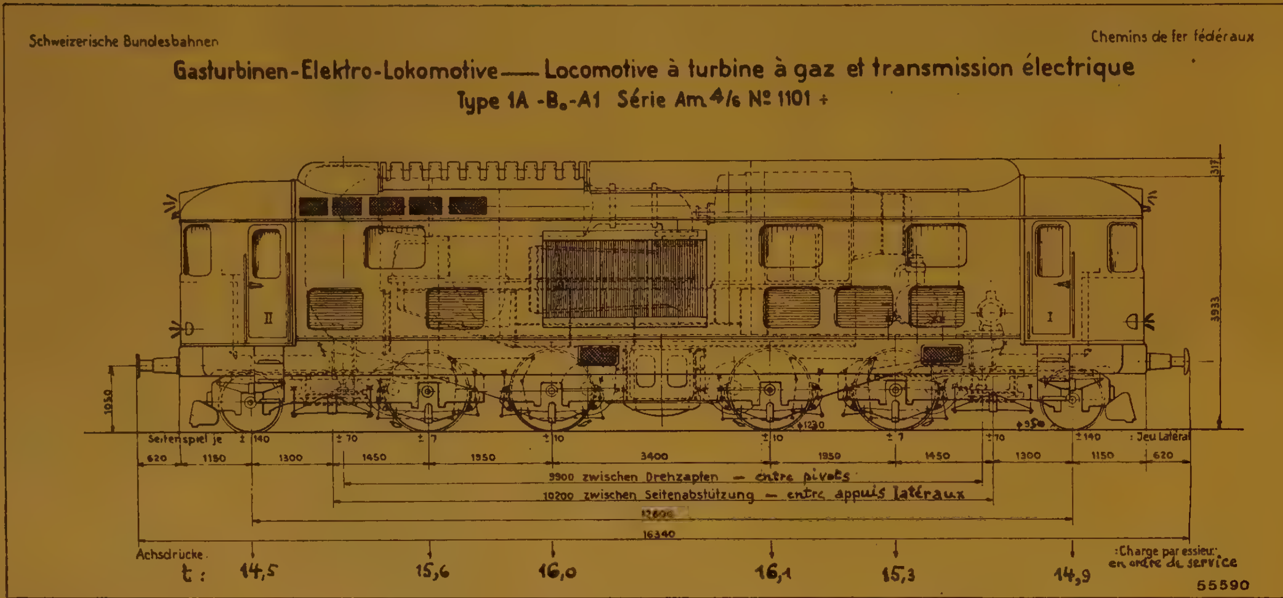


Fig. 170. — Gas turbine locomotive, type 1A-B_0-A1, series Am 4/6, No. 1101, Swiss Federal Railways. Sketch in elevation, showing axle loading.

Photo SLM-Winterthur.

Fig. 171. — Locomotive in fig. 170, hauling a train.

Photo Brown Boveri.

Fig. 172. — Combined carrying-driving bogie of locomotive in figs. 170 and 171.

been classified BCFe $^2/_8$, as an inseparable set with multi-unit control, with a driver's cab having the same number as the motor unit [see note ([81])]. See figs. 174 and 176.

c) three articulated twin sets on three bogies, of which two are driving, BCFZe $^4/_6$, Nos. 731 (BLS), and 736 and 737 (BN). These are the sets shewn in figs. 129, 131-133.

d) lastly, three *new* twin sets with four bogies fitted with the same flexible

drive, BCFe $^4/_8$, Nos. 741 (SEZ), 742 (GBS) and 743 (BN) were put into service in 1945/46 [106]. See figs. 175, 177-178. They can haul a drawbar load of 80 tons.

The electrical equipment of all these railcars, except the Fe $^4/_8$ (Nos. 791-2-3 of Oerlikon) was supplied by Sécheron.

Oberland-Bernois (MOB) Railway, narrow gauge, 750 V. DC, a direct line from Montreux through the Pays d'en Haut to Zweisimmen, placed in service six light railcars (on two driving bogies, i.e. four motors per car) of an hourly rating of 600 H.P., Nos. 3001 to 3006, type CFe $^4/_4$, for maximum speeds up to 75 km./h.

Photo NSB.

Fig. 173. — High speed triple motor set, CFmeo, 18535-38, Norwegian State Railways, NSB.

As for the mechanical parts, except for the bogies Fe $^4/_5$ of Nos. 791-796, which are from SLM-Winterthur, all these were supplied by the « Société Industrielle Suisse » (SIG) of Neuhausen (Shaffhausen) as already noted, or by SLM-Winterthur (Nos. 702 and 704).

14) From 1941 to 1944, the Montreux-

(46 m.p.h.) in service [107] (fig. 179) : stub hollow shaft.

15) From 1941 to 1943, the Gruyere Electric Railways (former CEG-, narrow gauge, 850 V. DC, placed in service three railcars, also with two driving bogies (with hollow shafts) per car, type Ce $^4/_4$, series 131, maximum speed in service

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[106] See « Light railcars of the Lötschberg (BLS) Co. », H. WERZ, *Bulletin Sécheron*, Geneva, No. 18, 1946. Also Nos. 17, 1945, p. 34, and 19, 1947, pp. 3-4.

[107] See *Bulletin Technique de la Suisse Romande*, Lausanne, 15th. Apl. and 13th. May, 1944, Dr. R. ZEHNDER, « Technical improvements on the MOB ». — *Revue Brown Boveri*, Baden, May 1942, pp. 267-270.

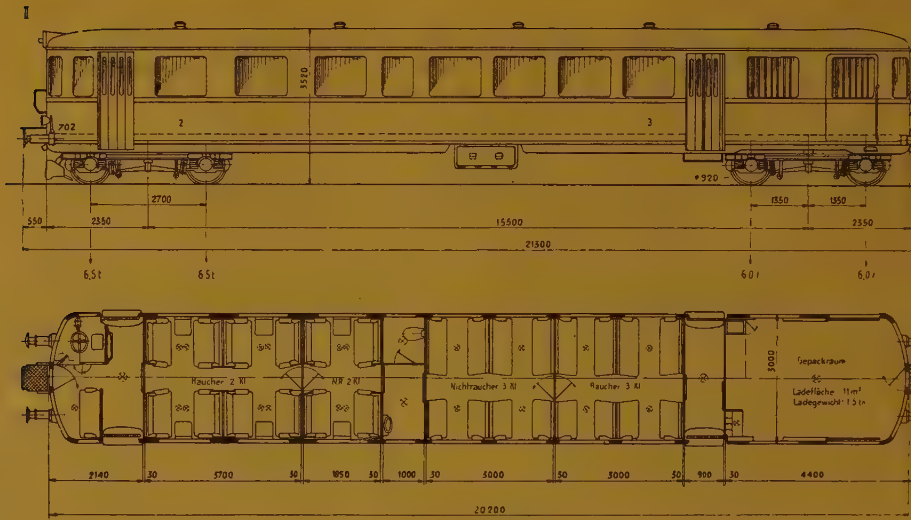


Fig. 174. — Motor sets, series 701, type BCFe ²/₈, BLS, made up of

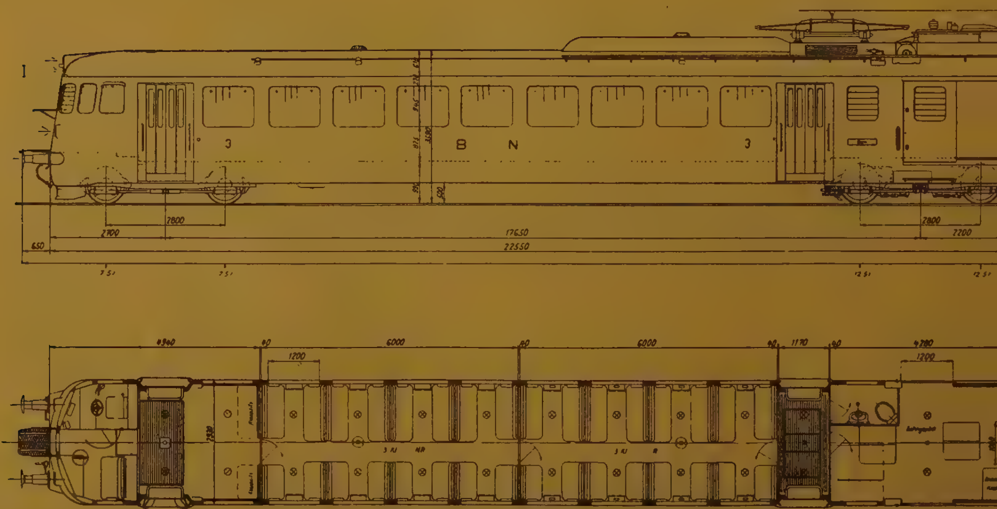
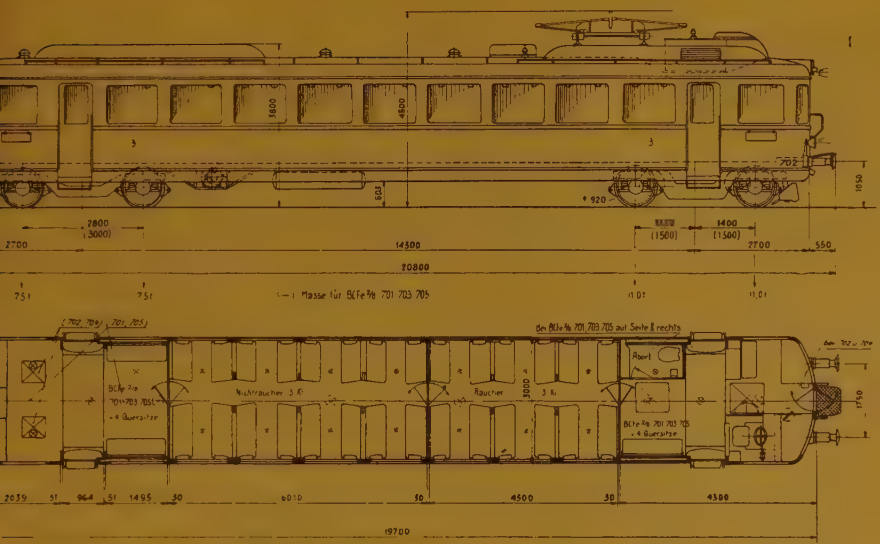
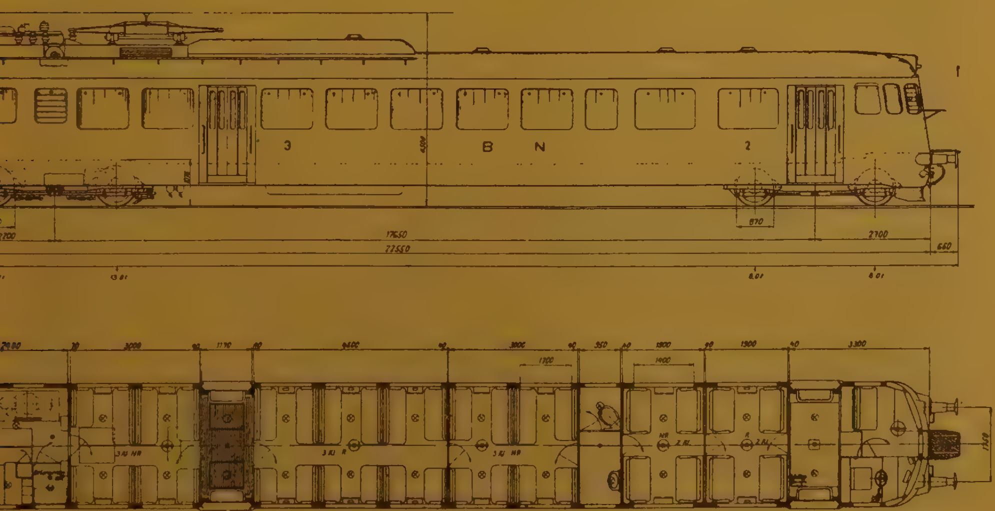


Fig. 175. — Dimensioned



Cliché Sécheron

coach and one trailer — these vehicles do not work separately.



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tion of BLS sets in fig. 177).

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Fig. 176. — Motor set, as fig. 174, now series 701, of BLS and lines operated by the BLS.

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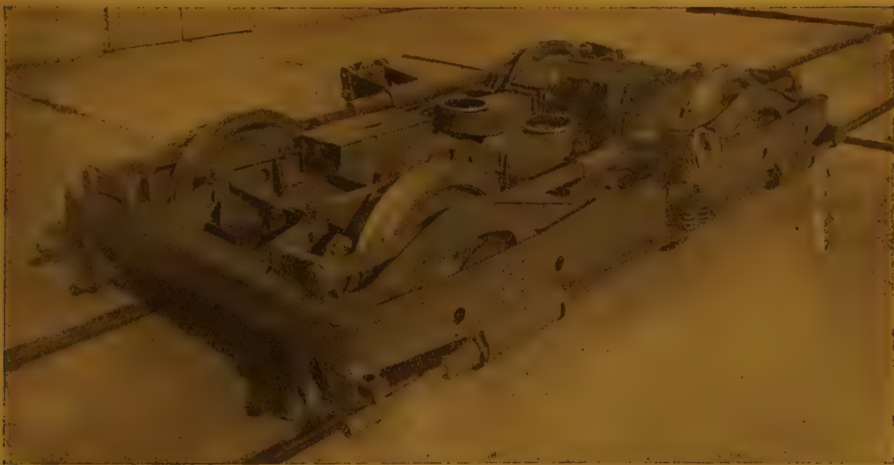
Fig. 177. — New double railcar sets, BCFe $^4/_8$, 4 bogies, the two central ones driving, Nos. 741-3, SEZ, GBS and BN lines respectively, all operated by BLS.



Cliché Sécheron.

Fig. 178. — Central driving bogie with torsion bar suspension (SIG-Neuhausen pattern) and mechanism for coupling with oil bath spring boxes, sets in figs. 175 and 177.

Fig. 179. — Light, narrow-gauge, railcars, 4 driving axles, series 3001, Montreux-Oberland-Bernois, MOB.

75 km./h. (fig. 180) ([108]). In 1942, the CEG was absorbed by the Freiburg system, GFM (Gruyere-Freiburg-Morat), which includes both normal and narrow gauges, single-phase and direct current, amongst its lines, as well as large omnibus services. Under item 18) we shall deal with the single-phase, normal gauge, cars of the Freiburg-Morat-Anet (formerly FMA, third rail, DC) and Bulle-Romont.

Fig. 180. — Metre-gauge railcar, type Ce $^{4}/_{4}$, series 131, Gruyere lines, GFM (Freiburg) Railway.

16) In 1942-43, the Val-de-Travers, a local line (RVT) in the Neuchatel district of Switzerland, metre gauge, single-phase current, 15 kV., 16 $^{2}/_{3}$ cycles, put into service two railcars, single driving bogies, stub hollow shaft. These cars, type BCFe $^{2}/_{4}$, Nos. 101 and 102, have an hourly rating of 600 H.P., maximum speed in service 75 km./h. They are similar to other cars in Switzerland introduced about the same time ([109]).

17) In 1943-45, the Yverdon-St. Croix Railway (Vaud Canton, Switzerland), metre gauge, single-phase current, 15 kV., 16 $^{2}/_{3}$ cycles, obtained from Brown Boveri (electrical equipment) and the « Société Industrielle Suisse » (SIG) of

([108]) See *Economie et Technique des Transports*, Lucerne, 1944, pp. 5-13, X. REMY, GFM, « Coordination et modernisation du matériel roulant aux Chemins de fer Fribourgeois ». — « Le nouveau matériel roulant des Ch. de fer Fribourgeois GFM » put in service in September 1943 on the narrow gauge lines of the « Gruyère », published by the GFM system in 1944. — *Revue Brown Boveri*, Baden, May 1942, pp. 267-270.

([109]) See *Der Offentliche Verkehr*, Berne, Nov. 1947, pp. 8-9 (Swiss Transport Union).

Neuhausen (mechanical parts) five railcars, all with stub hollow shaft, 3 type BCe $^4/_4$, Nos. 1 to 3 with two driving bogies, 600 H.P. hourly, tare 37 tons, and 2 type BCe $^2/_4$, Nos. 11 and 12, with one driving bogie, 300 H.P. hourly, tare 29 tons ([110]). The Yverdon-St. Croix line has gradients of up to 44 $^0/_{00}$. Figs. 181 and 149 shew, respectively, one of the cars in service on the line, and the mechanism, on an axle, dismantled. The electric brake is regenerative for braking the weight of the complete train.

Fig. 181. — Electric railcar, type BCe $^4/_4$, Swiss Yverdon-St. Croix Railway.

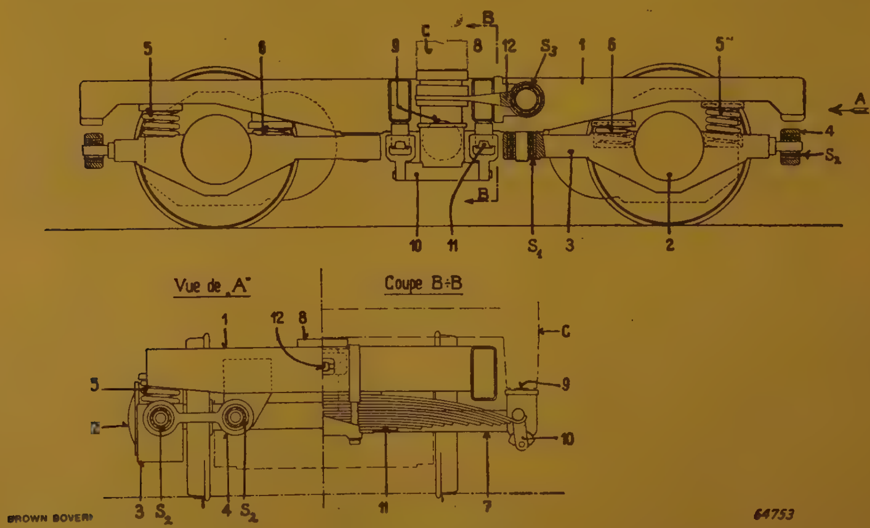
18) In 1945-46, the GFM (see item 15) introduced on the Freiburg-Morat-Anet and Bulle-Romont lines, eight railcars fitted with the same mechanism (fig. 182) of which one, No. 155, type BCFe $^2/_4$, has one driving bogie only (2 motors of 300 H.P. hourly rating), the other seven, type BCe $^4/_4$, Nos. 161-167 having four motors and a power of 1 200 H.P. per car. These cars are provided with a bogie of a new design (fig. 183), the « Simplex », built by Brown Boveri, as was all the electrical equipment. Bodywork was by SIG (Neuhausen) ([111]).

The bogie in fig. 183 was designed to give extremely smooth and vibrationless running, even at very high speeds. It is of relatively light construction whilst being very robust. All shock arising

([110]) Noted in *Revue Brown Boveri*, May 1946, p. 304 (German edn.). — Details will be published during 1948.

([111]) Details of these railcars will be published during 1948 by the GFM. — *Revue Brown Boveri*, Baden, Sept. 1946, pp. 249-250.

Fig. 182. — Normal gauge railcar, series 161, Swiss (Freiburg) GFM Railway, in service during winter.



Plan Brown-Boveri.

Fig. 183. — Driving bogie of car in fig. 182 (see text for explanation of symbols).

from track irregularity, or from entering curves at high speeds are heavily damped. This exceptionally smooth running has a most favourable effect on the whole vehicle, particularly the electrical apparatus. This is, in fact, subjected only to very slight vibration, resulting in less wear and tear and lower maintenance

charges. This quality also has its effect on the driving motors, since they can be provided with individual flexible drive and fitted rigidly to the bogie frame, the vibration of which is heavily damped. Moreover, since the unspring weight is reduced to a strict minimum, track hammer blow is greatly reduced, which is also favourable to maintenance.

part subject to rubbing. The rubber-mounted joints have no steel components bearing on each other. Maintenance costs are therefore reduced to a minimum. The lightness and solidity of the frame are the result of its fabrication from steel plate by electric welding. The frame is made up of hollow beams, fully sealed and very rigid. This type of bogie construction, in accordance with the most modern ideas, is therefore specially applicable for modern motive units for high speeds, or heavy railcars for the conveyance of passengers.

Fig. 184. — Light B_0-B_0 locomotive, type Re $^4/_4$, series 401, Swiss Federal Railways, hauling a light « Städteschnellzug » connecting the principal Swiss towns.

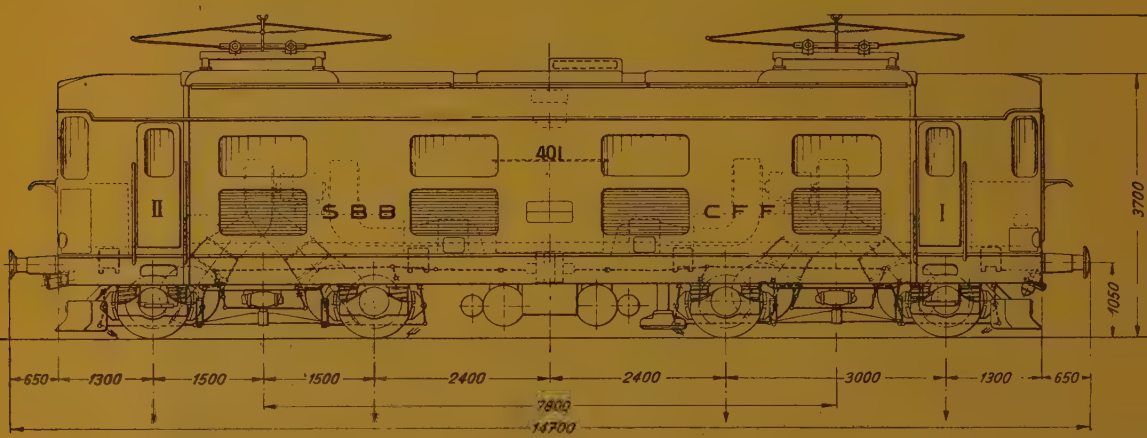
The qualities of this type of Brown Boveri bogie are due, basically, to the use in all joints of resilient « silent-bloc » mountings. These « silent-blocs » have been inserted to take up the play which normally exists in the joints. Shock is thus no longer transmitted, but is absorbed by the resilient « silent-bloc » between the members. This bogie is also notable in having no single

This « Simplex » bogie can be described as follows (see diagrammatic sketch, fig. 183).

The axles are located in roller bearings (2), situated in horns fixed at one

end to the bogie frame (1) by a « silent-bloc » (S_1). The rubber insert of this « silent-bloc » therefore allows the horn to move in relation to the frame. It provides especially for vertical movement. The other ends of these horns, that is the ends towards the front and rear of the bogie, are connected to the frame by a small rod (4), fitted transversely. This rod is also secured through two « silent-blocs » (S_2) and provides a flexible lateral guide for the axle. The horns themselves bear on the boggie frame through 2 coil springs (5 and 6) each.

The car body (C) is carried on the bogie by the bolster (7) with a pivot (8) at the centre to which is fitted the car body. Through this pivot to the body, and hence to the drawgear, is transmitted the tractive effort of the motors. The body also rests on the end of the bolster through rollers (9). These rollers are mounted on needle bearings. The bogie bolster is carried by rods (10) set rather obliquely, with two large transverse laminated springs (11). So that these rods should not transmit any tractive effort, they are provided with a special carrier (12) fixed at one end to the bogie frame and at the other end, through a ball joint, to the pivot. The carrier is fixed to the frame by a « silent-bloc » (S_3); the arrangement of the carrier can be varied according to the type of bogie, and therefore does not restrict the movement of the bogie bolster in relation to the bogie frame and will preferably be arranged as low as possible to avoid lifting of the bogie.



Cliché SBB-

Fig. 185. — Dimensioned sketch of locomotive in fig. 184, axle load 14 tons.

19) The Swiss Federal Railways, SBB-CFF, have had in service since 1946, some light B_0-B_0 locomotives, for haulage of fast light trains linking the

large Swiss towns (112). These are of a new, totally adhesive type, series 401, class Re $^4/_4$, 16 of which were in service at the end of 1947 (Nos. 401 to 416) and 40 under construction or on order (Nos. 417 to 456). No. 401 was put into service in 1946 (113).

they are more railcars than electric locomotives proper, the reduced rolling stock gauge being adapted to that of the new stock (112). The axle-load has been reduced to 14.2 tons, instead of 20/21 tons as with the large locomotives; the adhesive weight is therefore only

Cliché SLM-Winterthur.

Fig. 186. — Bogie, with motors, of locomotive in figs. 184 and 185.

57 tons, and their construction has been designed to give speeds of 100 to 125 km./h. (62 to 78 m.p.h.) in normal service [maximum speed on trials, 150 km./h. (93 m.p.h.)].

Fig. 184 shews one of these locomotives in service on the line, hauling a light train, fig. 185 a dimensioned drawing and fig. 186 one of the bogies. The mechanism of these locomotives has a stub hollow shaft, and is very similar to that shewn in fig. 150.

These engines are a quite new type;

The hourly rating of these locomotives is 2 300 H.P. or 575 H.P. per axle. The bogies are linked together by a special

(112) See *CFF Bulletin*, Berne, June 1937, « Les voitures en acier de construction légère », F. HALM, Eng. Traction CFF, pp. 84-92, 11 fig. and plans. — *I.R.C. Bulletin*, Brussels, May-June 1947, « The Swiss Federal Railways during the war », by G. DREYER (rolling stock), pp. 567-570. — *Economie et Technique des Transports* (formerly « L'Allègement dans les Transports »), Lucerne, Nos. 51 and 52, respect. March 1945, pp. 4 and 9, and Oct. 1945, pp. 40-44.

(113) See *CFF Bulletin*, Berne, March 1946, « Les premières locomotives de l'après-guerre des Chemins de fer fédéraux suisses », Dr. Ing. E. MEYER, Adj. Traction CFF, pp. 35-39 (6 fig.). — *Revue Brown Boveri*, Baden, No. 10-11 (special number) pp. 329-341. — *Neue Zürcher Zeitung* (technical supplement), Zurich, 6/2/1946. — See also the article by G. DREYER in Note (112).

device to reduce hunting [114]. The locomotives were built by SLM-Winterthur for mechanical parts, and electrical equipment was ordered from Oerlikon (MFO), Brown Boveri (BBC) and Sécheron (SAAS). The behaviour of these engines, in view of the purpose for which they were designed, has been very satisfactory and they may be considered a standard type.

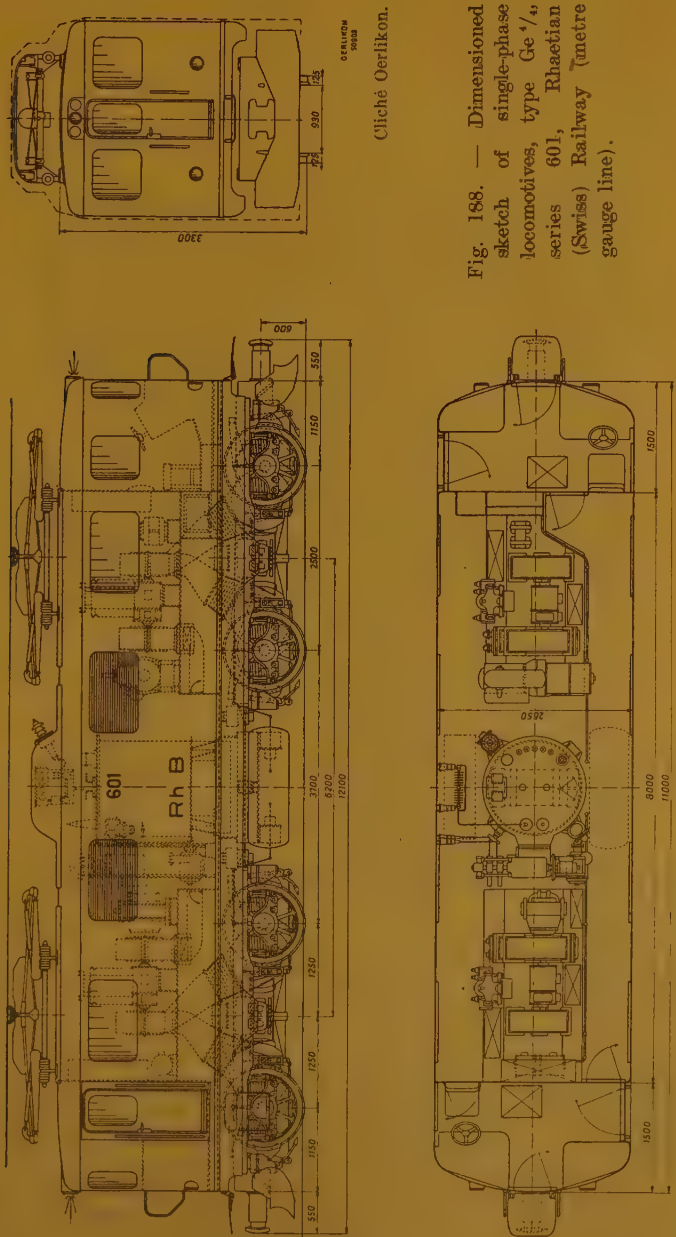
20) In 1947, the Vereinigte-Huttwil Bahnen, VHB, and Emmenthal-Thun, EBT, systems, already noted as the first result of the amalgamation of the various local normal gauge lines (Huttwil-Wohlhausen; Langenthal-Huttwil; Huttwil-Eriswil) and operated by the EBT, put into service 7 railcars (fig. 187) each with four driving axles, of an hourly rating of 1 100 H.P., maximum speed 90 km./h. (56 m.p.h.). These cars are type CFe $^4/_4$, bogies [115], Nos. 141 to 145,

Cliché Sécheron.

Fig. 187. — Single-phase normal-gauge railcar, type CFe $^4/_4$, Nos. 141-147, VHB and EBT (Swiss) lines.

(114) With regard to modern B_0-B_0 engines, particularly in Switzerland, see *Revue Générale des Chemins de Fer*, Feb. 1947, bottom of p. 40 and p. 41 (same author on behaviour of locomotives at high speeds).

(115) *Economie et Technique des Transports* (formerly « L'Allègement dans les Transports »), Lucerne, No. 65-66, 1947, « Nouvelles motrices à voyageurs des Chemins de fer Unifiés VHB et EBT », O. KREIS, pp. 2-6, 2 fig. — *Bulletin Sécheron*, Geneva, No. 19F, 1947, pp. 17-20, 6 fig., H. HEGETSCHWEILER. — *Revue Brown Boveri*, Baden, No. 1-3, 1947, p. 46 (German edn.).

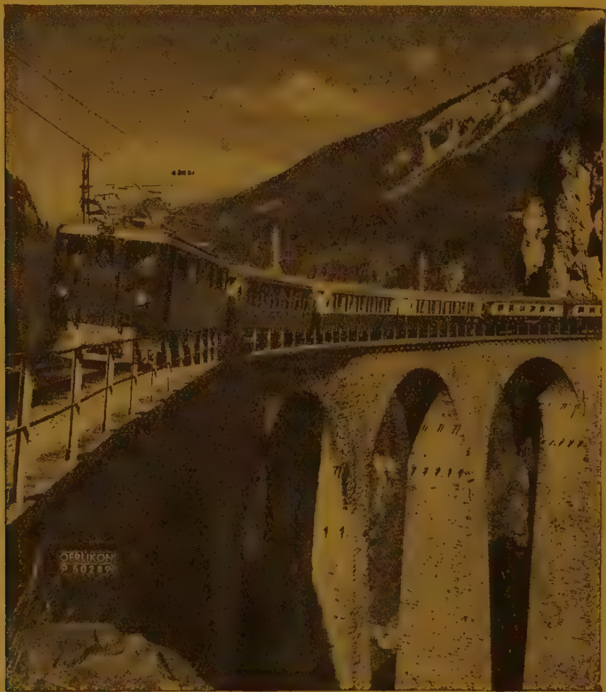


Cliché Oerlikon.

Fig. 188. — Dimensioned sketch of single-phase locomotives, type Ge $^{4}/_{4}$, series 601, Rhaetian (Swiss) Railway (metre gauge line).

VHB; and 146 and 147 EBT. They will be referred to in Chapter VII when dealing with new leaf-spring transmissions.

21) To complete, provisionnaly, this list we may note again the four 1946/47 B_0+B_0 type locomotives of the Rhaetian Railway, Rh.B., previously mentioned under 9) and in Chapter I, type Ge $^4/_4$, series 601, hourly rating 1 600 H.P., maximum operating speed 75 km./h. (46 m.p.h.), metre gauge, single-phase current, 11 kV., 16 $^2/_3$ cycles (116). Fig. 188 is a dimensioned sketch of one of these locomotives and fig. 189 is an engine in service with a train. The Rh.B. line has gradients of 35 to 40 $^0/_{00}$ on main lines and 70 $^0/_{00}$ on the Bernina and Coire-Arosa, all adhesive. The four locomotives, Nos. 601 to 604, were put into service in 1947 and appear to be giving satisfaction. Mechanical parts were supplied by SLM-Winterthur, electrical equipment by Oerlikon and Brown Boveri.



Cliché Oerlikon.

Fig. 189. — Locomotive in fig. 188, in service with train.

We shall note in the Appendix, the A1A-A1A bogie, gas-turbine, locomotive of Brown Boveri [see item 11)] and

(116) See *Bulletin Oerlikon*, Zurich, No. 260, Mar./Apl. 1946, pp. 1711-1712, 1 fig. — *Der öffentliche Verkehr*, Berne, Mar. 1947, pp. 6-7, 1 fig. — *Economie et Technique des Transports*, Lucerne, No. 73, Sept. 1947 (U.I.T. Congress, Montreux, number), p. 89, J. BERTSCHMANN (end of a study of the modernisation of the Rh.B. rolling stock).

No. 18000 of the Great Western Railway (now British Railways, Western Region).

To conclude this study of the Brown Boveri transmission through couples and coil springs, we will repeat a brief description issued by the firm which, together with fig. 190, will complete the remarks noted by the side of figs. 147 and 149. This coil spring drive, with oil bath, provides primarily for a considerable reduction in the number of unsprung parts. Through a pinion keyed to the armature shaft in the normal manner, the motor couple is transmitted to the gear wheel, running on plain or roller bearing on a stub hollow shaft fixed to the motor body. The driving axle passes through the hollow shaft with sufficient vertical play to allow for unevenness in the track. Displacement of the driving axle in the direction of travel being normally unnecessary, the axle space in the hollow shaft is made oval instead of round. This can be seen in fig. 190; furthermore, practically all recent applications

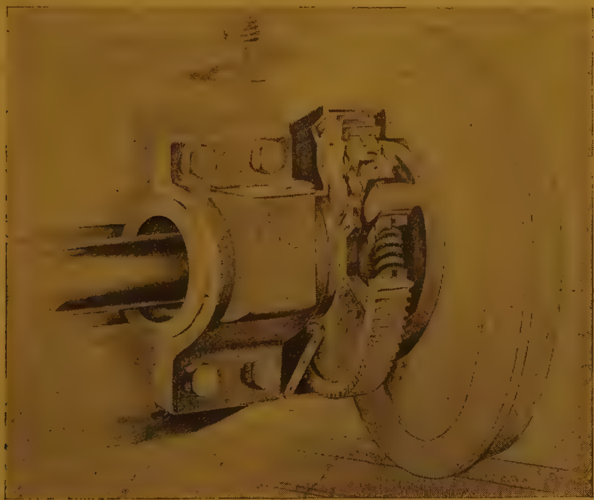


Fig. 190. — Sketch of coil spring mechanism, with oil-bath, by Brown Boveri (see figs. 146-150). The opening in the hollow shaft end (left) is a vertical oval.

Photo Ing. Ad.-M. Hug.

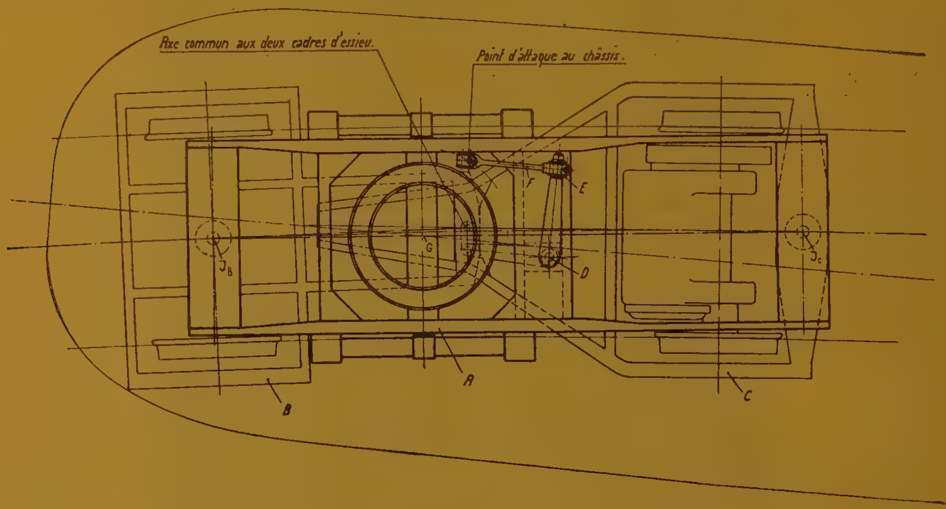
Fig. 191. — BLS railcar No. 721 (previously 787) of fig. 153, in service.

have had a stub-hollow shaft (right side of fig. 146).

Union between the driving axle and the large gear wheel is effected by a driving link keyed to one of the wheel studs or to the driving axle itself. To limit the compression of the springs, the arms of the driving link abut, at the end of the stroke, against the spokes of the large gear wheel casing.

This type of transmission is particularly suitable for high rotary speeds. Consequently, it also allows the use of very small diameter driving wheels, whilst maintenance is limited almost to oil changing. One of its principal advantages rests in its small volume, the mechanism being almost entirely contained in the gear wheel.

We mentioned under 2) and previously — see figs. 131 to 133 and text under fig. 133, left-hand column



Cliché Liechty-VRL.

Fig. 192. — Diagram showing axle guiding arrangement and bogie frame :

A = Bogie frame.
B & C = Individual guide frames for axles.
D = Vertical pivot, supporting the two levers forming a fixed angle.
E = Articulated joint to lever F, connected at the other end to *body frame* (« point d'attaque au châssis »).
G = Axis of the body underframe and the centre casting (pivot) for body bearing (see fig. 132 and 133).
J_B & J_C = Pivotal points for the individual axle frames.

the bogies with radial axles,

and would like to include a brief description of this interesting arrangement, confined to its relationship, however, with driving mechanisms and motor suspension. Figs. 129, 131, 132, 133, 146, 153 and 191 should be consulted. The 2 latter figures show railcar 787 (later

721) (117), type Ce $^2/_4$, Swiss BLS, already mentioned several times previously. This car has nose-suspended motors (*) without hollow shaft, similar to the Ce $^2/_4$, No. 701, « Flèche du Jura » — Jura Arrow — of the Swiss Federal (118).

Fig. 192 is a diagram of the arrangement for guiding moveable axles (119). A system of levers DEF compels the two axles of a bogie to pivot in the bogie frame, and to adjust themselves radially to the curve, following in a precise manner the mechanical action of the leading axle when entering the curve. The connection between the levers is such that the rotary movement of the body by comparison with the axis G of the body underframe, which is proportionate to the radius of the curve, involves a pre-determined lateral displacement of the common point of the two axleguards B and C and consequently causes a radial alignment of the axles.

Fig. 193. — Method of reinforcement by welding, on light railcar bogies.

Fig. 194. — Secheron helicoidal spring mechanism; hollow shaft with gear wheel and unilateral mechanism.

(117) See *Bulletin Technique de la Suisse Romande*, Lausanne, 21/12/35, pp. 305-307 (3 figs.). — *Revue Brown Boveri*, Baden, Mar. 1936, pp. 98-99 (W. LÜTHI). — See also Note (83).

(*) *N. B.* — This car was shown under item 2) (fig. 146 and following) in error as having Brown Boveri flexible gear; it has, in fact, two tramwayslung motors.

(118) See *CFF Bulletin*, Berne, Apl. 1939, pp. 52-55 (6 figs.), and Nov. 1938, p. 162.

(119) In addition to note (83), see *Revue Polytechnique Suisse SBZ*, Zurich, 1936, « Die Lenkgestelle des Leichttriebwagens 787 der BLS ». — *Bulletin Arbeitgeberverband Schweiz. Transportanstalten*, Aarau, 1936. — *Elektrische Bahnen*, Berlin, R. LIECHTY, 1937, « Neuer Triebwagen der Berneralpenbahn », then « Die Bewegungen der Eisenbahnfahrzeuge auf der Schiene und die dabei auftretenden Kräfte ». — *Verkehrstechnik*, Berlin, 1942(?), « Die vierachsigen Triebwagen der EAG, Schaftloch-Gmünd-Tegernsee », FÖRDERREUTHER. — *Glasers Annalen*, Berlin, No. 10, 1947, « Die SIG-VRL-Achssteuerung Bauart Henschel und ihre Bewährung an einer schweren elektr. Abraumlokomotive », K. EWALD, 6 p., 11 figs. — See Appendix.

The device is arranged in such a way that it is not influenced by transversal movement of the body of the vehicle.

The BLS-BN Company, which has undertaken these important applications, considers the *Liechty system good in principle*, but it is necessary that the levers and studs, controlling the forced positioning, should be fairly robust and also that the arms of the levers should be sufficiently strong to resist excessive wear. These details have had to be re-inforced. In the early stages, play was sometimes experienced with one of the axles, and this resulted in one of the four bogie wheels being subject to heavy tyre wear, whilst the other three were normal. The axles of the driving bogies on the sets shown in figs. 129 and 131 were, therefore, fixed in the normal parallel position for running on the straight. The central carrying bogies (fig. 133) retained their functions as radial axles, which, however, necessitated the large wheel base of 4.6 m. (15′ $1^1/_8$″).

Fig. 195. — As fig. 194, with the spider casing, which is fixed against the driving wheel and works on the axle, in position.

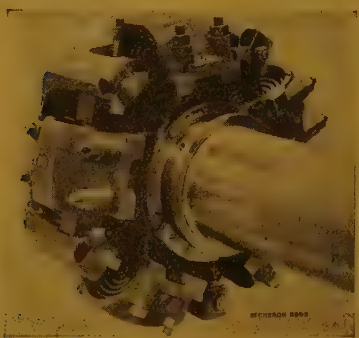


Fig. 196. — Near portion of fig. 195, seen from the gear wheel side.

As regards the « Flèche du Jura » railcar, put into service later, the radial axle mechanism has behaved satisfactorily.

The Author considers that this arrangement may have interesting possibilities in future applications.

Whilst on the question of special bogie arrangements, the *reinforcement of bogie frames* for light railcars may be examined. Fig. 193 shows the strengthened parts of a light railcar bogie.

In view of the importance of this question to railway Administrations, the following remarks are appropriate. Break-

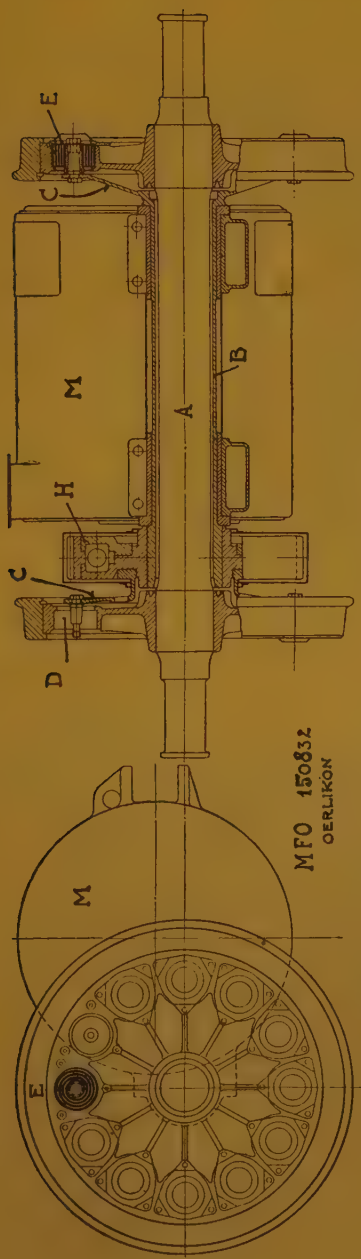


Fig. 197. — End view and cross section of axle fitted with Oerlikon helicoidal spring mechanism.
(For explanation of symbols, see text.)

ages should be avoided, even after strengthening (see between figs. 60 and 61) by welding (most carrefully!) the strengthening plates so that they cover the angles and the welding runs bevelled to avoid veins parallel to the zone of possible fracture. The arrows in fig. 163 show the points in question, the importance of which we must emphasise.

Before proceeding to new applications of laminated spring mechanism (figs. 113 and 114 and corresponding text) and its development, two trial applications — at present unique — may be mentioned, these having spiral — helicoidal — springs; one by Secheron (figs. 194 to 196) and one by Oerlikon (figs. 197 and 198). The Secheron mechanism was fitted early in 1948 to one axle of the triplet set, Swiss Federal Railways, type Re $^{8}/_{12}$, No. 691 (previously RBCFe $^{8}/_{12}$, No. 502), see figs. 134 to 139; it is arranged exactly to replace one of the push-rod mechanisms.

The arrangement may be briefly described as follows: the five sleeves carrying the springs are the same as those which, in figs. 130 and 139, are operated by the push-rods (see figs. 140 and 141). On the outside (opposite to the gear wheel) of the mechanism on the hollow shaft, the same sleeve blocks, in two parts bolted together, (figs. 138, 139 and 141) carry each, instead of coil springs, a helicoidal spring, one of which is shown separately in fig. 194.

This new flexible Secheron mechanism was made for an axle for the Swiss Federal Railways in 1941 and was fitted at the beginning of 1948 in the Zurich works of the CFF to one of the driving axles of the « Flèche Rouge » triplet railcar set, as already stated, for trial purposes. Its behaviour cannot yet be com-

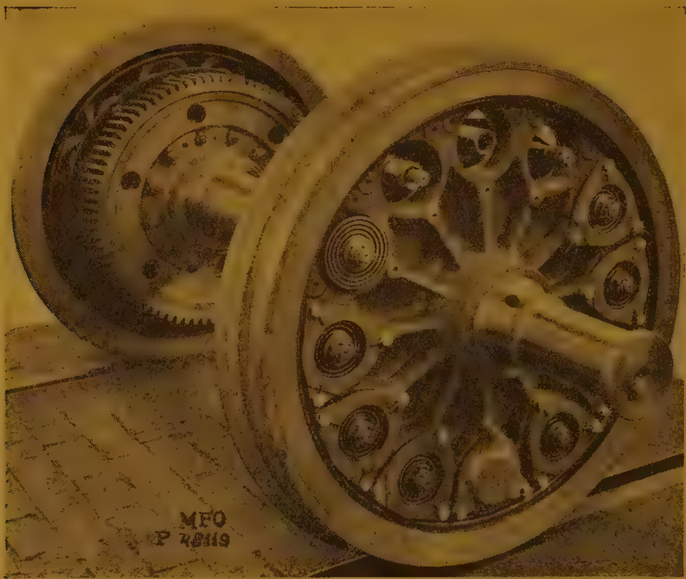


Photo Oerlikon.

Fig. 198. — Mechanism in fig. 197, fitted to a railcar axle.

Fig. 199. — Set of wheels for half unit of locomotive E.428.008, consisting of one driving bogie and guiding bogie with two carrying axles, Italian State Railways. This is the original Bianchi mechanism (see figs. 140 and 141 of **Cde. indiv.**) used on 12 2-C_0-2 locomotives (series E326, fig. 142 of **Cde. indiv.**) and 203 E428 (001-203) locomotives.

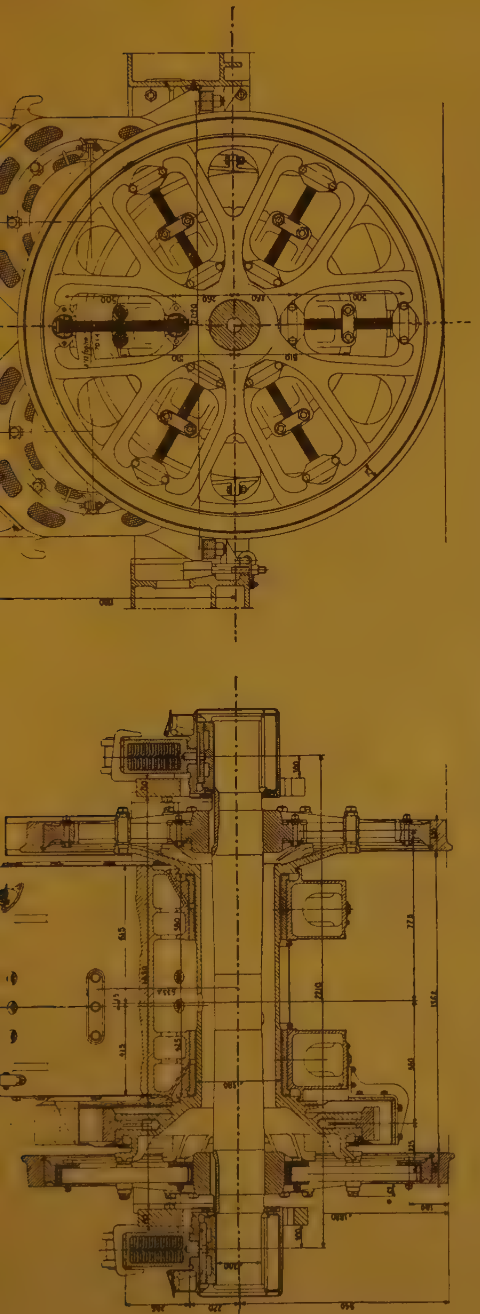


Fig. 200. — Vertical section through axis of motor and lateral view with twin motors, of the final Negri laminated spring arrangement, derived from the Bianchi mechanism (Italian State Railways).

mented upon. It will, however, probably have no further application.

As regards the other helicoidal spring mechanism, that by Oerlikon, shown in figs. 197 and 198, it was fitted in the autumn of 1943, and has remained in service since, on railcar Fe $^{4}/_{4}$, No. 18524 (new number 824) of the CFF.

It may be briefly described as follows (fig. 197) : the large gear wheel H, preferably having a flexible rim (see fig. 7) rests on the hollow shaft B and also on the motor body M. On the ends of the hollow shaft and therefore flanking the motor group and gears, against the centres of the driving wheels, are fitted membranes C, in the form of discs, carrying the spring pivots E; when at rest these pivots are centrally positioned in the sockets D. Transmission of a half-couple of the large gear wheel to the neighbouring driving wheel takes place through the play of the spiral springs; the other half of the couple is transmitted from the gear wheel to the opposite driving wheel by the hollow shaft and further play of the spiral springs. This mechanism, which has been removed for overhaul, will shortly be replaced in service in its established form, with *armoured rubber* in place of helicoidal springs. We shall return to this subject in the Appendix.

New mechanism with laminated springs.

Reference is made to the remarks under 6) (page with fig. 112) regarding figs. 113 and 114. On the following notes we shall deal with the two NEGRI type mechanisms, one of which (figs. 200 and 201) has laminated springs and the other (figs. 202 and 203) levers pivoted on coil springs; the latter has two applications, a locomotive type and a railcar

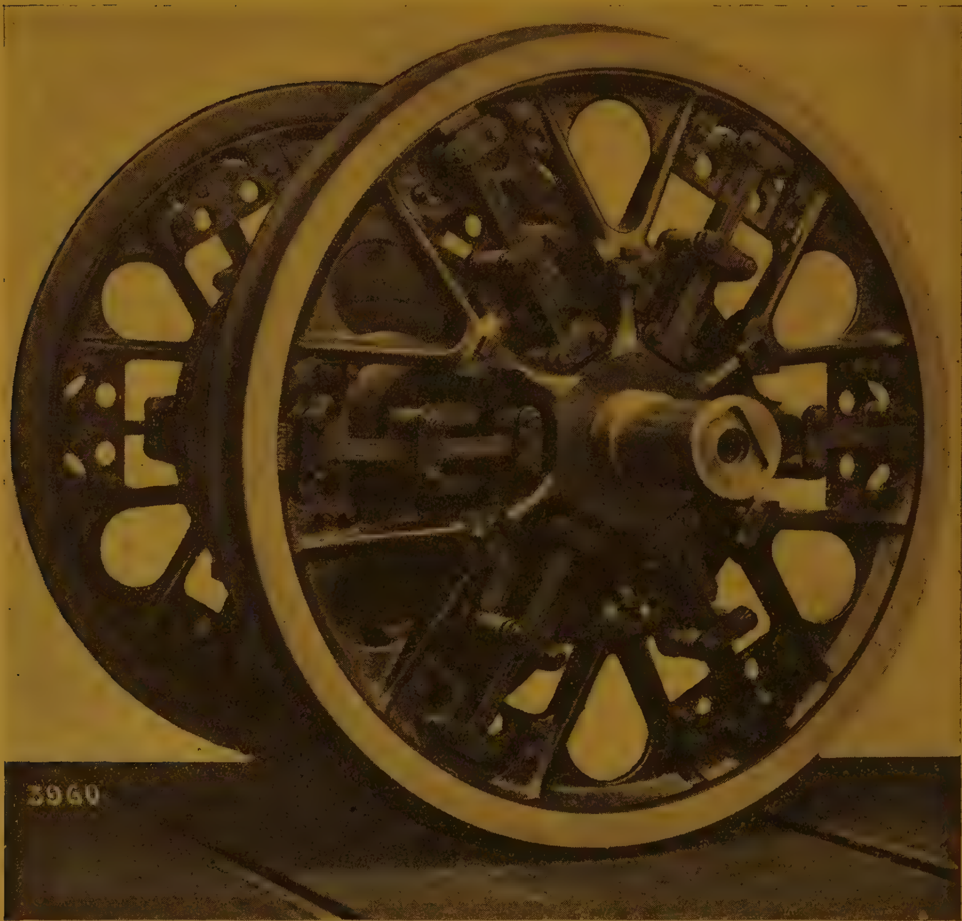


Fig. 201. — Driving axle and hollow shaft with Negri mechanism, similar to fig. 200. Bilateral control, unilateral gear. Trial arrangement with ends of springs between blocks. The horizontal springs are under slight deflection from the unsupported weight of the hollow shaft.

type. The two latter variations can be noted with coil spring mechanisms but we shall nevertheless describe them here, along with laminated spring types, since they relate to electric locomotives and railcars which are of the same types as those with laminated springs: they concern, in fact, the normal motor vehicles of the Italian Railways. All these mechanisms, and the locomotives and railcars with which they are concerned, have been described in more or

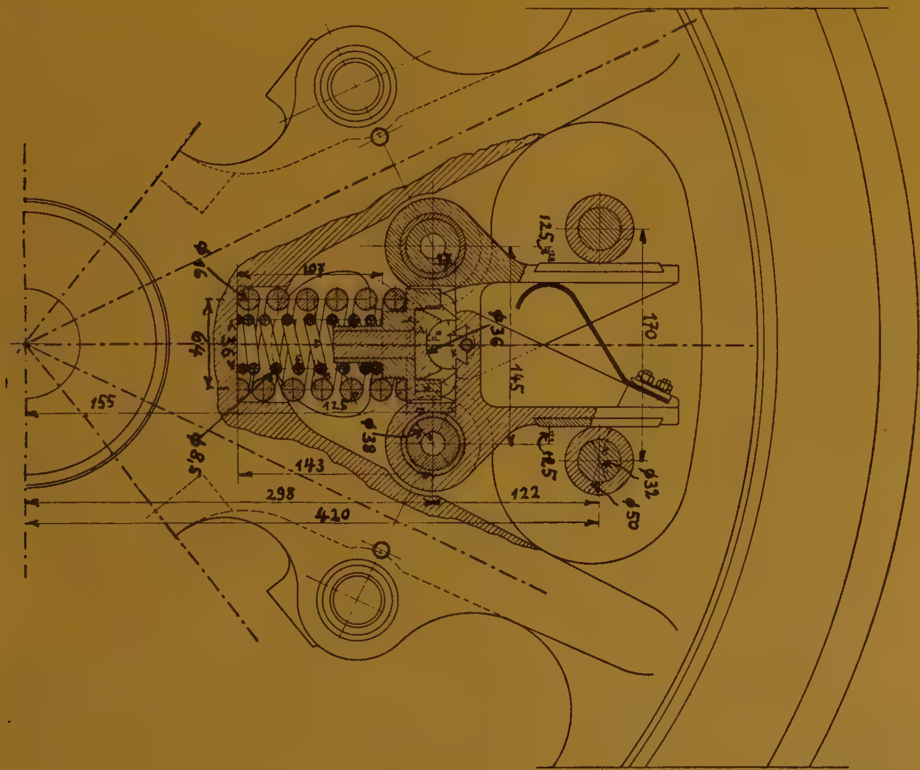


Fig. 202. — Vertical section — between two spokes of driving wheel (electric locomotive) with Negri mechanism, *variation* of pivoted levers, with coil springs (Italian State Railways). All dimensions are shown. Railcar pattern.

less detail, in technical publications (120).

In continuation of what has been stated under 6) on the page including fig. 112, fig. 199 shows the set of wheels from a half-locomotive, series E428, of the Italian State Railways, fitted with the original Bianchi mechanism. This completes figs. 140 to 142 of **Cde. indiv.** (121).

(120) See « Sistemi di trasmissione del movimento fra motori ed assi nella trazione elettrica ferroviaria », MARTINELLI, XLIV meeting of the Italian Electro-Technical Association, AEI, Bologna 1940 (61 figs.). This is based almost entirely on **Cde. indiv.** The arrangements mentioned here are noted on pp. 11-14, figs. 38-52, of the Martinelli article. — Publication 1935, by the Italian Transport Ministry — Railways — « Electric Traction on the State Railways — High voltage DC rolling stock » (in French, 50 pages, 41 figs.). — Bibliography will be completed in the Appendix.

(121) In regard to figs. 113 and 199 (apart from 140-142 of **Cde. indiv.**) we shall include in the Appendix two views of the strengthened Bianchi mechanism, E428 Italian State Railways. See also 2 views on p. 10 of the publication in Note (120).

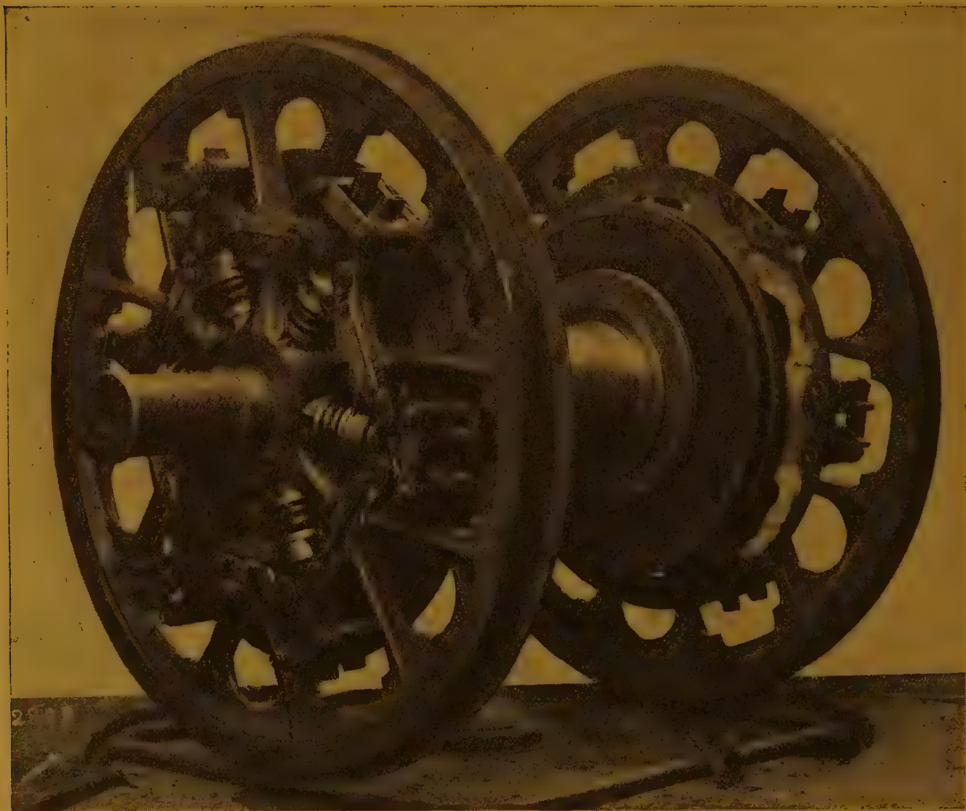


Fig. 203. — Fitted *locomotive* axle, with mechanism similar to figs. 201 and 202. Drive is bilateral in this case also, with unilateral gear. Trial arrangement for an Italian State E428 locomotive.

The NEGRI laminated spring mechanism is very similar to the BIANCHI mechanism. The laminated spring groups shown in fig. 113, instead of being rigidly held at the base, are fixed at their two ends in such a way that they can pivot to allow the ends to deviate from the centre line of the group in any direction, up to a certain angle; instead of being operated from the free end (tyre side in the case of the Bianchi) these springs are driven from the centre between the two roller bearings (for each set of springs).

Figs. 200 and 201 show this arrangement clearly; it allows an obviously considerable reduction in weight of the spring elements since the forces are distributed over the whole length of the laminations, the ends of which are able to take up an angle (to right or left) according to the direction of travel.

As regards behaviour and lubrication, it may be said that : as the sockets allow

the ends of the spring to pivot, they must naturally be lubricated, but this is not of prime importance in view of the extremely limited movement. The laminated springs are of course subject to

Photo Breda.

Fig. 204. — Driving axle, complete with motor and double reduction gears. Bianchi mechanism for railcars (see figs. 114 and 209).

lubrication, since it has less joints, and on the other hand the construction is simpler and the springs last longer as they are less stressed. The Italian State Railways (Locomotives and Rolling Stock Dept.) consider, however, that the two laminated spring arrangements (Bianchi and Negri) are very satisfactory.

The first experimental application of the Negri laminated spring mechanism was to one of the $2\text{-}B_0+B_0\text{-}2$ locomotives (fig. 199) of the E428 class (see fig. 201), but in this first application, the two end-supports (tyre side) of the spring sets were against the roller bearings, as with the Bianchi, whilst in the final assembly the ends are, as has already been stated (and as shewn in fig. 200) pivoted in cylindrical sockets.

This mechanism is obviously suitable

Photo Breda.

Fig. 205. — High speed light railcar set, series 201, type ETR [160 km./h. (100 m.p.h.) in service, up to 205 km./h. (128 m.p.h.) on test], Italian State Railways, at Florence. (35 1st and 59 2nd class seats, with dining facilities.)

fatigue and, at the points of contact (ends and centre) to wear. Experience has shown that the Negri laminated spring mechanism costs less in service than the Bianchi, on one hand because of

only for large-diameter driving wheels. The Italian State Railways consider, however, that it could also be adapted for freight locomotives. It has been used since 1936/37 on E428 locomotives

Nos. 204 to 242, GE636 locomotives Nos. 001 to 108 (all) and to E424 [122] locomotives Nos. 001 to 130 (all). This Negri laminated spring arrangement is therefore fitted to a total of 277 locomotives. Illustrations of some of these

Fig. 206. — Articulation of one of the sets in fig. 205 (central station, Rome Termini).

locomotives will be given in the Appendix.

We now come to *Negri coil springs :*

a) *for locomotives.*

This is very similar in operation to the arrangement just described. The only constructional difference is in the fact that the laminated springs are replaced by two concentric coil springs acting from the wheel hub through a pivot on two pivoted L-shaped levers, which bear on rollers fitted to the driving wheel centre. Fig. 202 shews this clearly (railcar type) with dimensions. Fig. 203 shews the mechanism fitted to a locomotive axle — E428 class. This, however, is a single trial fitting on one locomotive of the class [see fig. 199 and fig. 43 of the publication in note [120]].

b) *for railcars.*

Before dealing with the Negri coil spring mechanism *for railcars,* fig. 202, mention must be made of the *Bianchi railcar arrangement.* This mechanism was shewn in fig. 114, as it was first fitted to the « Elettrotreni » sets, series 201, type ETR, of the Italian State Railways [hourly rating 1 200 H.P., 6 motors, speed 160 km./h. (100 m.p.h.)]. Fig. 204 shews the same mechanism, with double gear reduction, on the complete motor axle group, the motor being fully suspended. These motor sets have already been fully described [123]. They

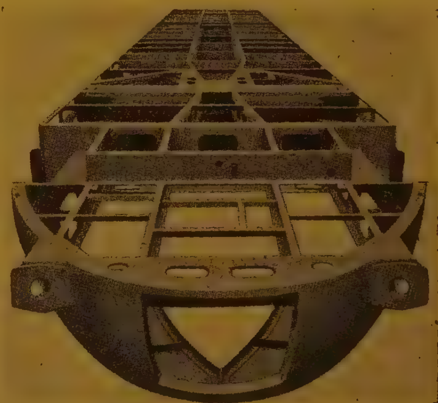


Photo Breda.

Fig. 207. — Frame (welded plate) of a leading vehicle of sets shown in fig. 205 and 206.

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[122] B_0+B_0 type engine, 72 tons, 1 400 H.P. hourly, 95 km./h. (60 m.p.h.), for passenger and freight traffic on lightly loaded lines. — It may be added that M. le Cav. NEGRI is an official of the Italian State Railways.

[123] See *I.R.C. Bulletin*, June 1939, pp. 612-613, report on question I, by M. L. DUMAS, on operation by railcar (this triple set is shown in the upper figure of p. 612 and the lower figure shows a railcar of similar arrangement of the Italian State Railways). — *CFF Bulletin*, May 1937, p. 73 (German edn.), illustration of the same sets. — Bibliography will be completed in the Appendix.

have been built since 1935 by the Breda Works [124] of the Sesto-S. Giovanni, Milan. Figs. 205-209 shew, respectively, of the first of sets (all with Bianchi railcar mechanism), a set in the station; the method of articulation; the welded case in the centre of the axle, with a stub hollow shaft (double gear).

This *Bianchi transmission* for motor vehicles has had the following applications :

1) the first 144 railcars with inside

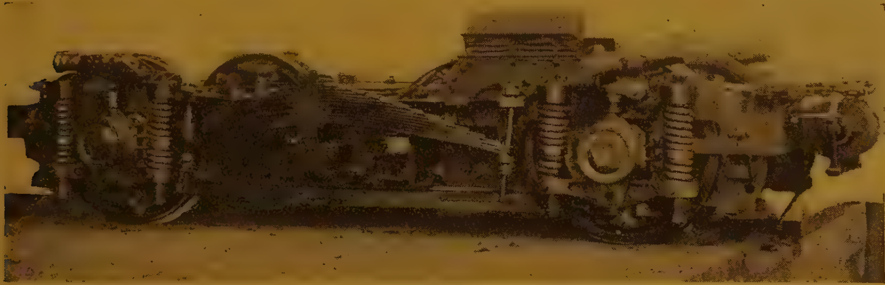

Fig. 208. — Leading, single motor, bogie of sets in figs. 204-207.

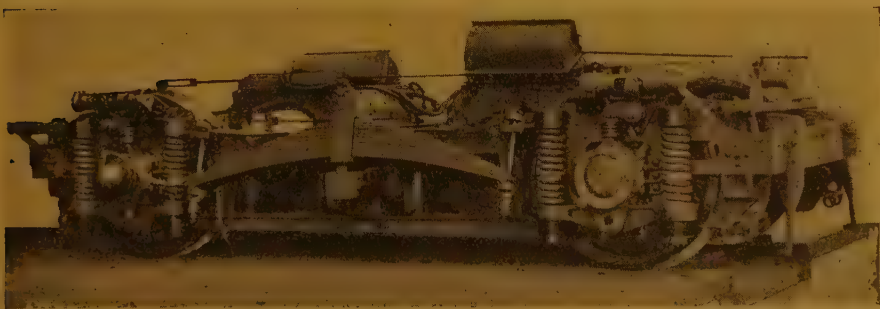

Fig. 209. — Intermediate (articulation) bogie, two motors, of sets in figs. 204-208 (see fig. 206).

plate frame of the leading vehicles; an end bogie (with one motor) and, finally, an intermediate bogie (with two motors).

Fig. 210 shews the same Bianchi mechanism for railcars, manufactured by FIAT, Railway Department, Turin. Flexible transmission is effected in this axleboxes [see fig. 146 of the publication in note [120]];

2) the first 14 express motor sets, Nos. 201 to 214, of the Italian State Railways (figs. 204 to 209).

We pass now to the details of the *Negri coil spring mechanism* for railcars.

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[124] Società Italiana Ernesto Breda per Costruzioni Meccaniche, already mentioned in Note [38] and p. 68 of Cde. indiv.

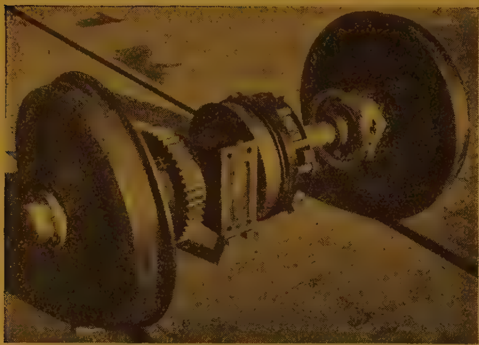


Photo Fiat.

Fig. 210. — Driving axle of railcar, Littorina type, with Bianchi mechanism operating on the centre of the axle.

Figs. 211 and 212 shew this mechanism. Contrary to what is shewn in figs. 202 and 203, the coil springs are, in view of the much smaller diameter of the driving wheels, in this case placed alternately with the levers and between them. Fig. 211 shews the axle with the complete mechanism on the hollow shaft

Fig. 211. — Negri coil spring mechanism, operating on centre of axle, for Italian railcars.

and the gear wheel, without the wheels (outside the bogie frame); fig. 212 shews an axle, mounted in the bogie, with the same mechanism, but without the outer rim and set against a brake drum.

The following applications of the mechanism have been made :

1) 46 successive electric motor coaches, with inside axleboxes [fig. 42 of the publication in note (120)];

2) express motor sets Nos. 215 to 218;

3) 80 electric railcars, « trains blocs », capable of hauling trailers [fig. 46 of publication in note (120)] and provided with bogies identical to those in figs. 208 and 209 but with gear ratio for lower

Fig. 212. — Mechasnism in fig. 211, fitted to axle and partly dismantled.

speeds, as opposed to the express sets mentioned under 2).

It is intended to comment further on these various railcars in the Appendix.

As regards behaviour and maintenance in service, this Negri radial coil spring transmission has shewn itself at first very heavy in lubrication and wear of joints and rubbing plates. Good results have, however, been obtained by using an oil-atomiser, with compressed air, which is operated by the driver and directs a jet of atomised oil over all the components of the transmission, which provides a frequent and effective lubrication.

This concludes a very long Chapter IV and we now pass to the subsequent classes.

(To be continued.)

Expanding cements and the auto-stressing of concrete,

by Henry LOSSIER (*).

(*Bulletin technique de la Suisse romande, Nos. of the 2nd and 16th August 1947.*)

It is a commonplace remark that there is nothing new under the sun.

This may appear to be an exaggeration when speaking of human thoughts and ideas.

Nevertheless when we consider closely certain innovations, we see very often that the leading idea which guided each particular inventor had already been thought of, to some degree, by one or more of his predecessors whose researches had often been brought to nothing by the want of certain materials or the lack of favourable circumstances in which to work.

The study of the history of inventions creates a feeling of sympathy for those who lost the results of so many efforts, and teaches a lesson in modesty applicable to even the greatest among our contemporaries.

When in the course of the 1914-1918 war, the Allies were carrying out a rather important programme of building barges and tugs in reinforced concrete, the idea appeared to many to be considerably ahead of the time, and yet the first example of anything made in this way properly speaking was in reality a boat exhibited by LAMBOT in 1855, some sixty years previously.

At the present time, it is the fashion both in the scientific world and the realms of imagination to occupy oneself with the problems of the multiple stresses and strains to which engineering and building materials are subject and particularly to the so-called *threefold action and reaction*, irregular or hydrostatic. Sometimes indeed we hear the question asked who is definitely the inventor of this all-round balanced condition. The reply is obvious. No rivalry between individuals is involved for the inventor is no other than God himself.

This threefold action and reaction reigns indeed throughout the entire natural world. The stars, the pebbles in the sea, in other words every object submerged or buried is subjected thereto.

Experiments carried out over half a century and more ago on fragile materials, such as crystal, cast iron, ceramic products and concrete, have served to prove the remarkable properties of resistance and ductility derived from this characteristic. A sphere submerged in the sea at infinite depth would lose doubtless considerably in volume but would not collapse under any pressure, however great, so long as it had no hollow space within it.

This question of the natural stresses and balance of forces leads us as a matter of course to that of setting up *artificial prestresses*, that is to say the art of imparting to engineering works stresses opposed to those which they will be required to support in everyday service. In this sphere of action, it is no longer to God but merely to man that credit is due for the conceptions involved.

The fisherman of ancient times who bound his reed rod tightly with weed

(*) Lecture delivered at Zurich on February 1st, 1947, under the auspices of the *Bridge and Girderwork Section of the Swiss Association of Engineers and Architects.*

to prevent it from splitting was even then making use of the principle of prestressing. The cooper who hoops his casks, the wheelwright who heats his metal tyre before putting it on a wooden wheel, the manufacturer who applies hoop armouring to his cannon barrels, all do the same thing.

The old builders of wooden bridges, notably in Switzerland, often achieved remarkable things, contriving to put certain parts of the structures under initial compressing to prevent any play arising between the assembled parts, and the first engineer who conceived the idea of placing transverse chains in the masonry arches, put under tension by means of screw bolts, contrived to obtain a triple artificial prestressing.

Nearer to our own day, about half a century ago, we find the names of RITTER, RABAUT, CONSIDÈRE and others using various ideas associated with the problem of applying artificial initial loads to certain engineering works with the object of controlling their behaviour in service.

It is a curious fact, and one worthy of notice, that the idea of *prestressing mechanically engineering components or assemblies,* which has been commanding attention for some years now, preceded by many years the first designs of HENNEBIQUE, which marked the beginning of the practical development and application of reinforced concrete.

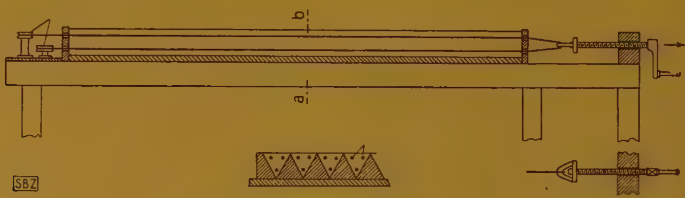


Fig. 1. — The pre-stressing process of Doehring (1888).

Some fifty-eight years ago — in 1888 in fact — a Berlin engineer named DOEHRING, took out a patent for making the components of fire-proof flooring. This was made of cement, armoured by applying wires put under a *very strong tensile load,* to use DOEHRING's own expression, before being wound on, and then maintained in that condition during the setting of the cement. The wires were put under load by means of turnbuckels and return pulleys, as shown in principle in *Fig. 1.* They were later cut off at the extremities and the assembly removed from the mould.

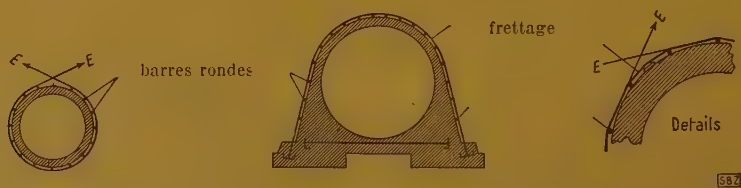


Fig. 2. — Piping with pre-stressed armouring on the Emperger system (1923).
barres rondes = round bars. — frettage = armouring.

About thirty-five years later, towards 1923, EMPERGER of Vienna designed and made hydraulic piping for high pressu-

res by armouring tubes or conduits prepared beforehand with rodding prestressed by mechanical or thermal processes. He got rid of the friction between the armouring and the concrete by interposing pieces of round iron, as shown diagrammatically in *Fig. 2* (1).

Having arrived at this point in my paper, passing over certain ideas of limited importance, I ought, to keep to the order of development of the subject, to mention the important work done by M. FREYSSINET, to which it affords me pleasure to pay due tribute here. This work being however known to you, I cannot do better than refer you to the writings of its distinguished originator.

M. COYNE, builder of several of our largest *dams* in France, conceived the idea of improving the stability of certain of them by installing metal stay rods anchored in the rock and subjected to a tension of the order of 80 kgr. per sq. mm. (50.79 Engl. t. par sq. inch) by means of hydraulic jacks.

In the realm of *piping and conduit* work I may mention the interesting achievements of Professor CHALOS, relative to a siphon under the Seine at Chatou near Paris which make use of a special double prestressing process thought out by him.

As will be seen in *Fig. 3* sections of tube moulded in advance are used as in the case of EMPERGER's work (1).

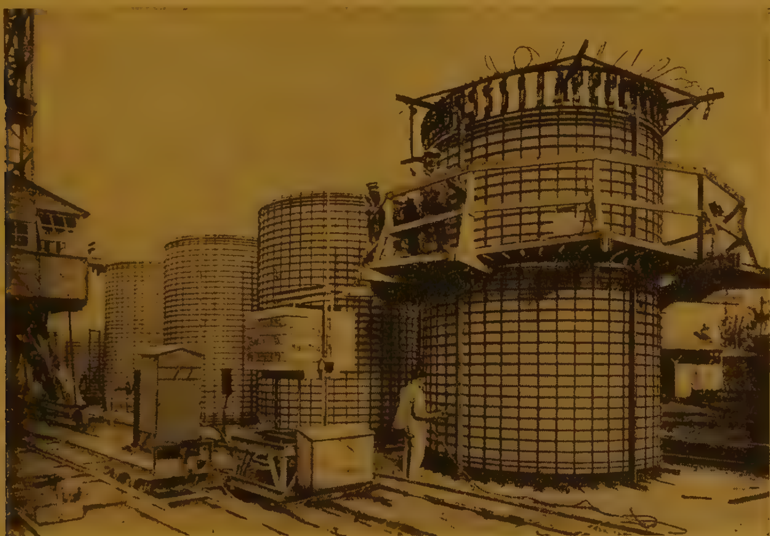


Fig. 3. — Moulds made in advance and subjected to double pre-stressing on M. Chalos's system for the Chatou siphon under the Seine.

(1) He used ordinary steel for this armouring, raising its elastic limit by hammer hardening. However, in a note which appeared in 1923 in *Beton und Eisen*, he proposed to use hard steels, working at relatively high loads, having a tensile strength apparently of the order of 120 kgr. per sq. mm. (76.19 Engl. t. par sq. inch).

(1) The longitudinal prestressing is obtained by means of flat bars of mild steel put under tension by jacks.

The diametral effect is got by means of hard steel hoop armouring put under tension, not as is done by some engineers tangentially but on the contrary *radially*, which has the

We may also mention under the subject of *bridge* building, the form of prestressing or more strictly « post-stressing » conceived by DISCHINGER who uses suspension bridge cables placed in the hollow portions of the structures and transmitting their loads through articulated rod connections arranged to eliminate all frictional effects. These cables are put under tension by special jacks. As all parts are accessible *it is possible to proceed to make adjustments at any time so as to compensate, as and when required, for the unfavourable effect produced by contraction and by any change in the characteristics of the concrete and the steel.*

The Aue bridge was built on this process. It comprises a cantilever span of 69 m. (75.459 yards).

In these two cases the concrete sections are subjected to a *uniform* degree of compression without bending, under a permanent load, and are not subjected to any tractive effects when carrying an overload.

We may mention also the system of auto-prestressed armouring invented by M. CHALOS, a professor at the French Ecole des Ponts et Chaussées, which works on the same principle as a bicycle brake [1].

I myself apply a method of mechanical prestressing which is very simple and consists in forming each girder or element out of two articulated sections connected together by the armouring itself.

By lining up these sections by means of a jack the armouring is put under

Fig. 4. — Auto-pre-stressed reinforcing element designed by M. Chalos.

effect of eliminating all tendency to slip and hence all idle frictional movements.

The pressure of the outer armouring elements prevents any displacement of the longitudinal bars simply by bringing into action their frictional effect against the concrete which allows all anchoring at the ends to be dispensed with.

The use of very simple forms of material enables a strict control over the entire process to be obtained.

[1] Each rod is formed of a metal tube made of woven wire put under tractive load on a flexible core with two elements being then welded or soldered at the ends. These armouring elements, which can be rolled up for carrying about, are incorporated in the concrete which is to be prestressed, then when the latter has reached a sufficiently hard stage are cut away from it at the ends. No hook or other anchoring is necessary owing to the powerful hold of the concrete on the woven wire tube. *Fig. 4* shows an armouring of this kind.

pre-load. A locking key piece then makes the system fast under this condition and all that remains to be done is to cover the bars so produced with their coating of material. *Fig. 5* shows one of the phases of the operation which requires neither special anchorages nor direct action on the armouring elements.

It takes hardly more than a minute to effect the prestressing of each girder or bar.

However the idea in itself could only have any practical interest to the extent that there were available to me types of cement which not only contracted during the process of hardening, as is the case with the mixtures commonly used, but also on the other hand a capacity for *expanding*, appreciably greater than such shrinking. I therefore turned my thoughts towards the *expanding types of cement*.

Fig. 5. — Pre-stressing of girder ont the Lossier system.

This rapid preliminary survey brings me to the heart of my subject, the *auto-stressing or self-stressing of concrete*.

* * *

After having endeavoured from 1924 to make use of the EMPERGER processes to obtain the double and triple stressing of concrete, I came to consider using from 1925 an entirely different method. While the different processes used since 1888 consisted in compressing the concrete by forces acting *from outside*, I had in view on the contrary the possibility of *provoking an expansion of the concrete itself in every direction and then making use of its expansive force either to put the armouring under load or to exercise a screwjack effect against masonry or earthworks, or to act in any other way.*

Have I had any predecessors in this line of thought ? It is possible that I have, but I am unaware of any.

After consulting our teacher and expert, Henry LE CHATELIER, I approached a number of French firms, of whom one, the POLIET and CHAUSSON works, were willing to interest themselves in the matter on a new basis.

The names of their associates HENDRICKS and PERRÉ, then that of Professor LAFUMA, are connected with the practical perfecting of the manufacture of the present expanding cements.

Composition of expanding cement.

These cements are obtained in principle by mixing three known elements, which are stable in themselves :

1. An artificial Portland cement, which forms the *base* of the mixture;

2. A sulpho-aluminous cement, which acts as the *expanding constituent;*

3. *A stabilising element,* the entry into action of which, delayed intentionally, holds back the expanding action by

absorbing the principal reactive, that is the sulphate of lime. This stabilising element is in general formed from the slag obtained from the furnaces.

The judicious apportioning of the three components, the *base*, the *expanding element*, and the *stabiliser*, allows of the expansion being regulated, both as to intensity and time, with a degree of exactness remarkable in a matter of this kind.

The properties of expanding cements.

The principal characteristic of these binding materials is *their property of being able to acquire a stable expansive effect in a constant medium, an effect which is in practice controllable as to intensity and time.*

The *amount of expansion* can attain, in the case of a pure cement paste, a figure of 50 mm. ($1^{31}/_{32}''$) per metre, or

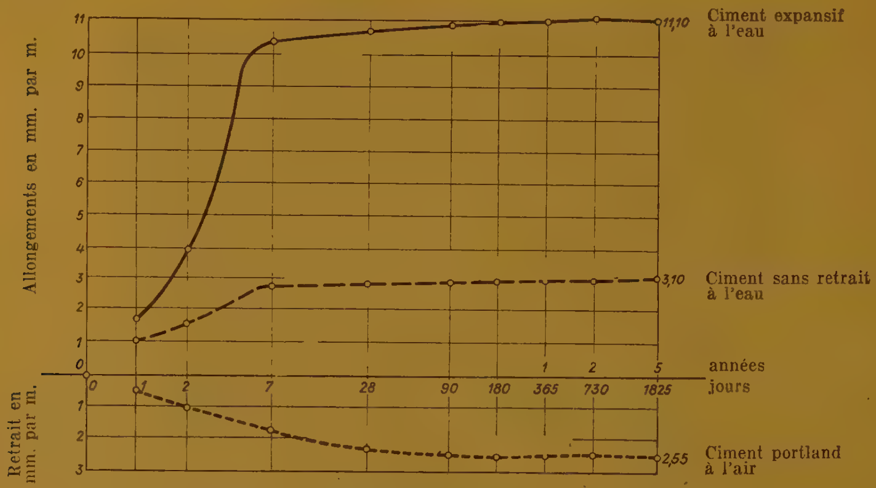


Fig. 6. — Elongation and contraction as function of the time and method of keeping the material.

Explanation of French terms:

Retrait en mm. par m. = contraction mm. per m. — Allongements = elongations. — Ciment expansif = expanding cement. — Ciment sans retrait = non-contracting cement. — Ciment Portland = Portland cement. — A l'eau = in water. — A l'air = in air. — Années = years. — Jours = days.

In addition, as we shall see later on when considering practical applications, we have also available a direct means of regulating this process in the course of executing the work, at once simple and effective.

I leave aside intentionally the special details of the manufacture of cements, which are the exclusive concern of manufacturers and chemists.

As to the way in which expansion is brought about, I refer you to the theory of M. PERRÉ.

the twentieth part of the initial length.

The *time taken* by it can be regulated between a minimum of twenty-four hours and a maximum of about 30 days.

In actual practice, to simplify the process of manufacture, we produce two principal qualities of material, namely :

a) *A cement having a small amount of expansion, and known as the « non contraction »* type, that is one having an initial expansion of 3 to 4 mm. per metre ($^1/_8$ or $^5/_{32}''$) on a pure mixture, substantially equal to the contraction

which occurs in the course of time and which it compensates;

b) An expanding cement, properly so called, of which the expansion on a pure mixture is in general of the order of 10 to 25 mm. per metre ($^{25}/_{64}$ or $^{63}/_{64}''$).

The amount of time occupied by the process of expansion, that is during which it increases progressively in humid surroundings before becoming work since, while it is in progress, the concrete must be maintained in a sufficiently humid state to bring about the reactive forces of expansion.

As regards the actual process of expansion, this is given in *Figs. 6 and 7*.

Fig. 6 relates to *material kept in water*, the expansion being shown as ordinates and the time in logarithmic abscissae. The curves giving the expan-

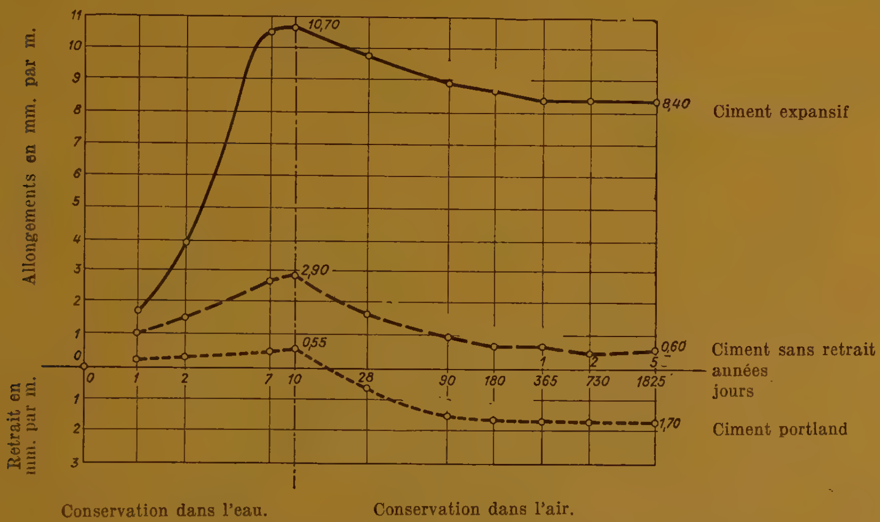


Fig. 7. — Elongations and contractions of various cements kept 10 days in water, then in air.

Explanation of French terms:

Retrait en mm. par m. = contraction mm. per m. — Allongements en mm. par m. = elongations mm. per m. — Ciment expansif = expanding cement. — Ciment sans retrait = non-contracting cement. — Ciment portland = Portland cement. — Années = years. — Jours = days. — Conservation dans l'eau = while kept in water. — Conservation dans l'air = while kept in air.

stable in constant surroundings is in general set at between ten and fifteen days for test pieces in pure mixture kept in water.

A greater rate of expansion would have the disadvantage of bringing the expansion force into action before the cement had acquired a sufficient amount of resistance.

Too slow a rate, however, would give rise to difficulties in carrying out any sion are in full line for an expanding cement, in broken line for « non contraction » and are dotted in the case of ordinary Portland cement, kept in air.

It will be observed that the non-contraction and expanding cements concerned, kept in water, show amounts of expansion of 3 to 11 mm. per m. ($^{1}/_{8}$ to $^{7}/_{16}''$) respectively which become stable in about ten days, the performance being watched over a period of five years.

By way of comparison we have shown the curve referring to a Portland cement kept in air which exhibited a contraction of 2.5 mm. (0.09844 inch) during the same period.

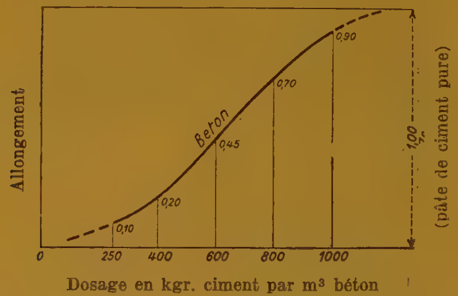


Fig. 8. — Relative elongation of a concrete as function of the quality of cement contained in it.

Explanation of French terms:

Dosage en kgr. ciment par m³ béton = amount of kgr. of cement per cubic m. concrete. — Allongement = elongation. — Béton = concrete. — Pâte de ciment pure = pure cement mixture.

Fig. 7 shows that if the test pieces, after remaining for eight days in water, are kept in dry air they suffer their normal rate of contraction which has to be deducted from the expansion. In this way, the expansion of the so called « non-contracting » cement practically cancels out, the two processes compensating each other, while the expanding cement becomes stable with an elongation of between 8 and 9 mm. per m. ($^{5}/_{16}$ and $^{23}/_{64}$″).

The intensity of the expansion in the case of *concretes* naturally diminishes in proportion to the amount of expanding cement which they contain.

If the expansion of pure cement mixture is taken as unity, we get in general practice expansion of the order of :

0.90 for concrete having 1 000 kgr. (2 204 lbs.) of cement;

0.70 for concrete having 800 kgr. (1 543 lbs.) of cement;

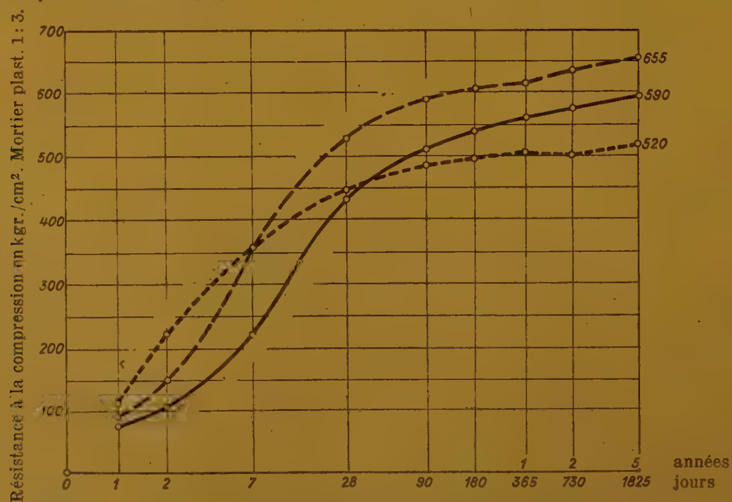


Fig. 9. — Resistance as a function of the time of a normal type mortar made with various kinds of cement.

Explanation of French terms:

Ciment fortement expansif = strongly expanding cement. — Résistance à la compression en kgr./cm². Mortier plast 1 : 3 = Resistance to compression in kgr. per sq. cm., Plastic mortar 1 : 3. — Années = years. — Jours = days.

— — — — Non contracting cement.
- - - - - - - - Portland cement.
▬▬▬▬ Strongly expanding cement.

0.45 for concrete having 600 kgr. (1 323 lbs.) of cement;

0.20 for concrete having 400 kgr. (882 lbs.) of cement;

0.10 for concrete having 250 kgr. (551 lbs.) of cement.

These proportions vary in addition according to the quality of the cements concerned.

Fig. 8 shows the rate of rise of the curve representing these relations.

When concrete expands under *some counteracting restriction,* plastic deformations are produced which diminish the intensity of the phenomenon, as we shall see later on.

Fig. 9 in which the *resistances to compression offered by the normal type of cement* mortar are indicated as ordinates and the times concerned as logarithmic abscissae, shows that the expanding cements, as compared with the Portland type, suffer a certain diminution during expansion at the end of which their resistance becomes equal and then definitely superior to that of the basic type.

As regards the *impermeability* of the expanding cements, it is — the proportions of the mixtures being equal — plainly superior to that of the other cements, which is of great advantage, even in the case of everyday classes of work, especially as regards the protection of reinforcements against atmospheric effects.

Two precautions have to be observed, however, when making use of them :

— in the first place, expanding cements are more sensitive to deterioration by exposure to the air; this is why they are ordinarily supplied in bags having a tarred paper lining or covering;

— secondly, having an extra amount of SO^3 in their composition they are equally sensitive to the accidental presence of sulphates. In like manner, the sands and gravels used in the making of mortar and concrete must not contain any.

Finally the present types of expanding cements are not yet classified officially as among those which offer resistance to the action of sea water or water containing sulphates.

If the temperature is raised considerably at the moment when expansion

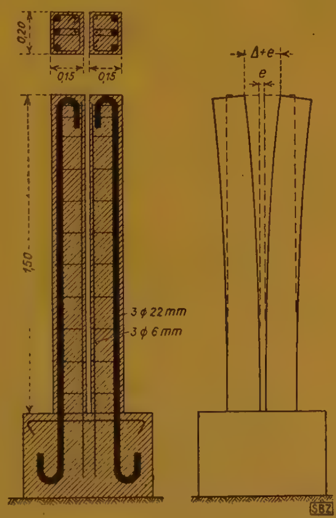


Fig. 10. — Test prisms placed back to back, dissymmetrically reinforced, before and after expansion of the concrete.

commenced, either by applying steam or hot water, it tends to diminish the intensity of the process while at the same time increasing the resistance offered to it at the outset.

The action of cold is relatively less noticeable.

The first experiments with expanding cement.

Our very first experiments were essentially *tests made to prove a principle, or afford a practical demonstration* of

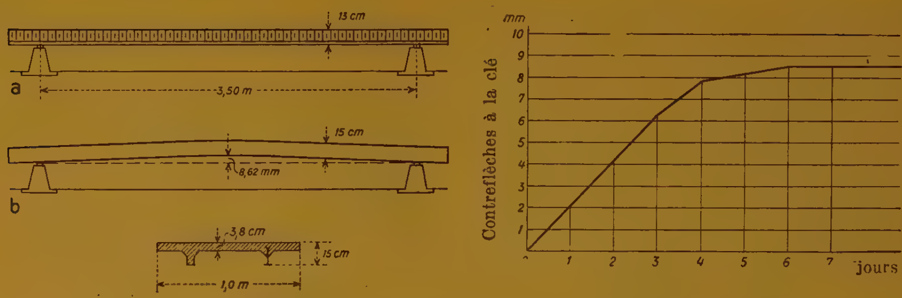


Fig. 11. — Test with a piece of flooring formed of two Christin metal girders connected by a cross-member in expanding concrete.

Explanation of French terms:

Contreflèches à la clef = counter versines at the top of the bowed portion.

what could be done. We may mention the following :

a) *Two prisms,* so-called, measuring 15 cm. (5$^{29}/_{32}$″) wide and 20 cm. (7$^{7}/_{8}$″) thick, placed back to back, were reinforced disymmetrically, as shown in *Fig. 10.*

The outer reinforcement consisted of three bars of 22 mm. ($^{7}/_{8}$″), the inner of three of only 6 mm. ($^{15}/_{64}$″).

Under the action of the expansive force of the concrete used to make them, they curved outwards *(Fig. 10).* The space between them, equal to twice the longitudinal versine of each, reached about 15 mm. ($^{19}/_{32}$″) after a fortnight. Exposed to the outer air and general conditions of weather for over four years, the distance between the prisms has not varied by more than about 15 %.

b) An *arch,* on a reduced scale, measuring 0.04 m. (1$^{9}/_{16}$″) thick, 1.50 m. (4′11$^{1}/_{16}$″) span and 0.075 m. (2$^{61}/_{64}$″) rise, that is having a lift of 1/20, was constructed in a medium expanding cement.

This arch flattened out automatically from the first day and in a week showed a steady counter-rise of 19 mm. (¾″) at the keystone point with no trace of cracking.

This counter-rise represented a quarter of the initial rise. In an arch of 100 m. (328′1″) span of the same form, the automatic counter-rise would be of the order of 1.25 m. (4′1$^{7}/_{32}$″).

There is no need to say that this was purely a demonstration experiment and that we should work with far more moderate figures in ordinary practice.

c) *A piece of flooring,* 3.50 m. (11′ 5$^{13}/_{16}$″) long, formed of two Christin type metal girders connnected by a cross-member in expanding concrete *(Fig. 11).*

Under the action of the expansion of the cross member alone, this floor piece bent itself automatically from the first day and took up a counter versine equal to 2 mm. ($^{5}/_{64}$″) at the centre of its length. This figure increased to over

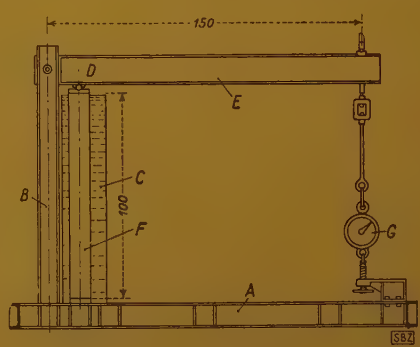


Fig. 12. — Faury machine.

8 mm. (5/16″) after five days humidification. Under load tests an overload of 1 040 kgr. per sq. m. (213 lbs. per sq. ft.) was required to bring the under surface of the curved girder pieces to a horizontal position.

Apparatus for checking the performance of expanding cements.

In addition to the equipment in common use with all forms of cement we have made use of two special types of apparatus :

— the first, designed by M. Faury, is intended to *measure the expansive energy*.

It consists *(Fig. 12)* of a rigid base plate A, a vertical member B and a pivoted horizontal arm E, with its bearing in the vertical member and a dynamometer G at its other end.

The prisms to be tested, measuring 10 × 10 cm. (3 15/16″ × 3 15/16″) in section and 1 m. (3′3 3/8″) long, are placed in a watertight container C, which can be filled with water. They have link connections, top and bottom, enabling the loads on them to be centred correctly. Two flexometers D allow of the elongation of the test pieces being measured.

This apparatus enables us to determine the forces at work under loads, and the constant or variable elongation, as well as the coefficient of elasticity of the various concretes under stresses of long or short duration. We make use of it notably to arrive at the dynamic expansion curve which will be referred to in the section on calculations;

— the second apparatus *(Fig. 13)* serves *to deal with the condition arising in arches and bowstring elements*.

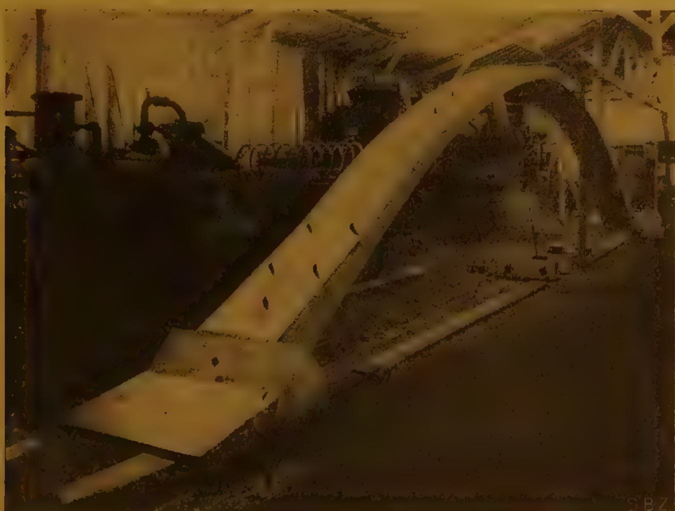


Fig. 13. — Model of a 12 m. (39′ 4 ½″) span arch.
The two abutments are connected by tension regulators of adjustable length with dynamometers and measuring instruments.

It consists of a fixed abutment piece and a moveable one. These are connected through tension regulators of variable length to dynamometers. A model of an arch of 12 m. (39′4 1/2″) span is seen

under test in the figure. By keeping the distance between abutments constant, we reproduce the case of arches on fixed abutments. By varying it we can deal with the cases of arches having tension regulators, or resting on elastic or plastic supports, or multiple span arches.

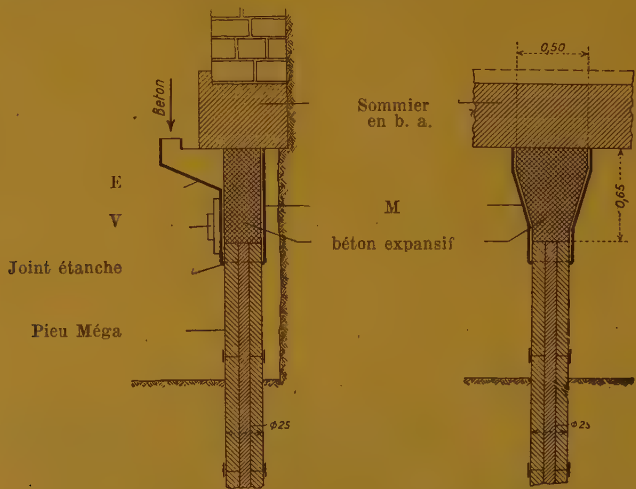


Fig. 14. — Underpinning of the Palais Ribour at Lille.

Explanation of French terms:

Joint étanche = watertight joint. — Pieu Méga = Méga type pile. — Sommier en b. a. = girt of reinforced concrete. — Béton expansif = expanding concrete.

Fig. 15, 16 and 17. — Underpinning of the Palais Ribour at Lille. Different stages of the work.

Applications of expanding cements.

Our first investigations into expanding cements were made twelve years ago and were directed towards perfecting the processes of manufacture and making sure of their stable qualities, as well as their other characteristics, as influenced by the passage of time.

With cements, more than with anything else, no result should be looked on as definitely obtained until it has been confirmed by observations extending over a sufficient length of time.

The applications of expanding cements to which in particular the French National Railways have offered considerable scope and opportunities, can be of many kinds, but our time being limited, I will confine myself to explaining just a few selected from among the most typical we have carried out.

a) Underpinning of foundations.

1. The question arose of *underpinning* the walls of an *historical building*, the *Palais Rihour, at Lille*, the foundations of which were showing signs of weakness. The system selected was that of the « Méga » pier or pile made by the firm of FRANKI.

We may recall that this pile is made up of elements moulded in advance in reinforced concrete and put together on site. They are driven into place by jacks. The delicate point consists, when the depth of driving has been reached, in putting the pile under load beneath the wall while making sure of perfect contact between them. This is usually done by using a special piece, forged in U form, a jack, certain locking devices, and then making fast under the girder by hammering.

The use of expanding cement has allowed of this operation being considerably simplified.

Above the head of the last element of the Méga pile *(Fig. 14)* a metal removable mould M is placed fitted with a spout E through which the concrete can be poured and a vibrator V.

A light reinforcement having been placed in the mould, this was filled up and agitated until the liquid concrete flowed through between the mould and the girder and filled the space. After it had set and the mould had been withdrawn the piece exposed was humidified for a few days to the degree required to bring about the desired initial thrust beneath the wall, of the order of 20 tonnes (19.684 Engl. tons) per pile.

This process, compared with the preceding method, allowed us to obtain a better degree of solidity in the head and body of the piles and to save about 20 kgr. (44 lbs.) of carefully worked reinforcement per element.

Figs. 15, 16 and 17 show the various stages of the operations.

The holes seen in *Fig. 17* are for allowing the water used to humidify the expanding concrete to penetrate to the inside. Expansion does not take place, in fact, until, some hours after the setting has ended, humidification is begun.

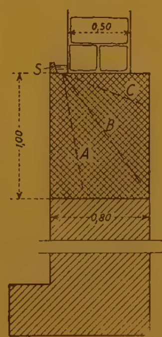


Fig. 18. — Underpinning a wall at the Ministry of Colonies in Paris.

If, while the expansion is in progress, this is suddenly stopped the expansion will itself cease *definitely* after 24 or 48 hours, after exceeding from 10 to 40 %, according to the proportions of

the mixture, the elongation reached at the moment when this is done.

Stopping the process of humidification thus forms a means of *regulating the expansion* on site, at once simple and effective.

2. *Fig. 18* illustrates an *under-pinning arrangement* adopted in the case of *a wall at the Ministry of Colonies in Paris.* On each foundation block made of ordinary concrete a head piece was formed in expanding concrete measuring 1 m. (3′3$^{3}/_{8}$″) high. The humidification holes A, B, C, 30 mm. (1$^{3}/_{16}$″) diameter, placed 20 cm. (7$^{7}/_{8}$″) apart, formed by leaving in temporarily some steel bars which are withdrawn as the concrete is setting, communicated directly with a supply of water contained in a simple plaster of Paris surround.

The expansion force ensured that the foundations were put on load under the wall without the aid of jacks.

3. We may note in passing the number of important applications of expanding cement possible in mine workings and grouting operations around tunnels and galleries. Important experiments are at the moment in hand in these directions.

b) Springing and keying of concrete and masonry arches.

You all know the classic procedure adopted for removing the load of an arch by using jacks acting at the soffit with a force equal or slightly superior to the horizontal pressure of the arch at the moment of doing so.

This operation entails three distinct principal stages :

— putting the jacks under load;

— filling the space between them with concrete;

— removing the jacks after the concrete has set sufficiently;

— filling up the joint space left where the jacks were placed at first.

Now, with *expanding cement* these *four stages* are reduced to a *single one.*

It suffices to put in place, in a channel or keying arranged in the soffit of the arch, after the main body of the latter has hardened sufficiently, *a filler key-piece or voussoir, made of expanding cement which plays the part of a jack made integral with the mass of the structure.* This allows us to compensate for:

— the elastic shrinkages of the concrete caused by the permanent load;

— all or some of those brought about by contraction and plastic deformations arising in the concrete in the course of time;

— if need be, all or some of the deformations arising from accidental shocks.

In the case of large structures several such expanding filler pieces can be provided, distributed throughout the length of the arch in an order laid down in advance.

Referring here to a bridge with reinforced concrete arch carried out in France for the Bridge and Highways Department of Eure-et-Loire, we give two views :

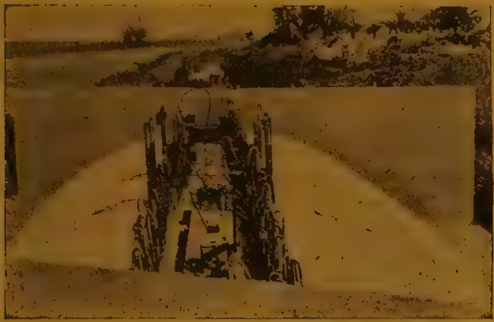
— *Fig. 19* shows the channel in the head of the arch to receive the expanding filler piece or key, the reinforcements in the arch being temporarily removed;

— *Fig. 20* shows the top of the expanding filler-piece and the openings provided to allow the water used for the process of humidification to penetrate into the body of it.

The MANET-RABUT appliances for measuring the intensity of the expansion can likewise be seen.

Another typical example is seen in the *repairing of the Poix Viaduct,* carrying the double line from Rouen to Amiens.

This masonry structure has twelve full arch spans resting on tall piers 18.50 m.



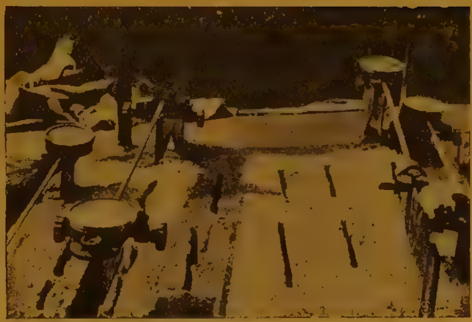


Fig. 19 and 20. — Bridge in the Department of Eure-et-Loir.

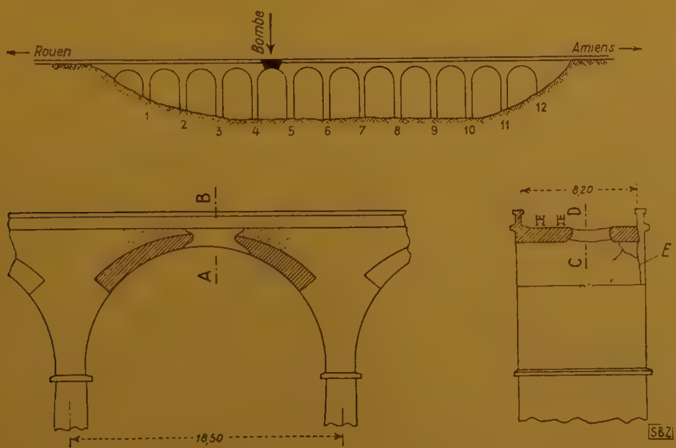
($60'8\frac{5}{16}''$) centre to centre *(Fig. 21)*. The arches are 0.90 m. ($2'11\frac{1}{2}''$) thick at the soffit.

In 1940 this viaduct was rebuilt to some extent by the Edmond Coignet concern, four arches and two piers having been partly damaged.

In 1944, during an allied raid, a bomb passed through the fifth arch in the neighbourhoud of the soffit of the transverse centre line.

Train working having been re-established on a single line by the use of two stout metal girders at the side of the breach, the repair of the structure was arranged as follows :

An inner arch staging of ordinary form having been put in position under the span concerned, the surrounding edges and faces of the breach are cut away and trimmed so as to get rid of the loosened parts of the masonry and at the same time provide normal surfaces of support to the two replacement rings, of unequal length and about 2 m. ($6'6\frac{3}{4}''$) wide. Each ring has in the middle of the breach a gap or channel, of about 1/14th of the length of the ring



Coupe C-D

Coupe A-B

Fig. 21. — Poix viaduct.

Coupe = section.

itself. In this the expanding filler-piece or voussoir has to be made for the purpose of putting the ring under pre-compression in the breach in order artificially to give it an active function of a similar kind to that played by the ordinary parts of the arch.

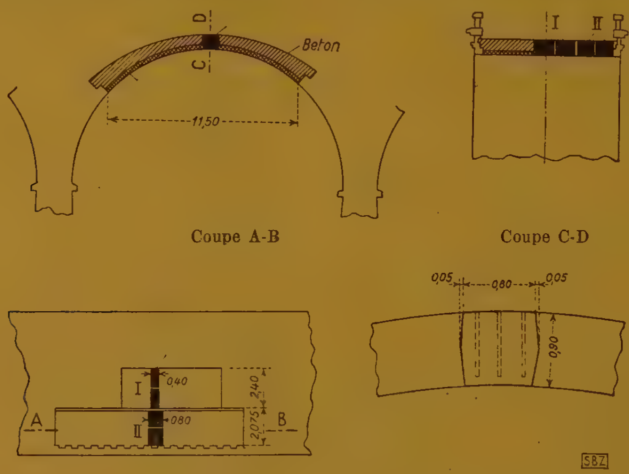
In other words, the initial expansive force must contribute to counteract the contraction caused by hardening and the creep of the rings in the course of time, while at the same time distributing equally over the whole breadth of the arch the permanent stresses.

The ordinary parts of the rings were carried out in concrete formed with common artificial cement, with inner faces in concrete lightly armoured, in order to preserve the external appearance of the damaged arch *(Fig. 22)*.

In the most recent work done by us this filling up process involves using the cement known as « non-contracting » in which the initial expansion compensates substantially for the contraction occurring in the course of time.

The expanding filler pieces or voussoirs had an irregular hexagon shape. They were made on May 17th, 1944, in sections of about a metre wide, separated by joints of very small width, in order to allow for transversal expansion. A few connecting bars of small diameter were placed, in two directions, near the contacting surfaces.

The expansive force necessary to meet the ends in view having been calculated, the intensity and the expansion called for were determined experimentally by the Faury apparatus, already described.



Coupe A-B — Coupe C-D — Vu par dessous — Coupe verticale

Fig. 22. — Poix viaduct. — Details.

Coupe = section. — Vu par-dessous = seen from beneath.

As I have already pointed out at the commencement of these remarks, the regulation of the intensity on site is a very easy matter, for, in order to bring about the expansion of these special cements, all one need do is to humidify the mass at the time of the setting of the material. If, while expansion is going on, the normal length of which is generally between five and fifteen days, humidification is stopped, the expansion ceases to progress at the same

rate and in about 48 hours will become stable, according to a known law.

In these conditions, the expansion is regulated on site merely by stopping the humidification as soon as the necessary value has been reached, allowance having been made for the correction covering the stabilising process after that occurs.

At the Poix Viaduct the expanding filler pieces were pierced with holes about 25 mm. ($^{63}/_{64}''$) diameter placed at 0.25 to 0.30 m. ($9^{27}/_{32}''$ to $11^{13}/_{16}''$) in the two directions and terminating a few millimetres from the under face of the arch. A small plaster of Paris surround, encircling each filler piece on the top of the arch held a sufficient quantity of water for humidification. To stop that process it suffices to pierce the film of concrete at the ends of the holes by the under face of the arch with an iron rod, or to siphon the water out. As arranged, humidification was stopped at the end of five days, the expansion required, 2.7 mm. (0.10634 inch) per m. being then present on the top face of the arch and shown on the Manet-Rabut instruments fixed on the filler pieces.

Another example of repairing damaged arches is that of the *bridge at Epinay-sur-Seine,* near Paris.

This double track structure comprises three masonry arches of 38.5 m. (126′ $3^{11}/_{16}''$) clear span and 1.35 m. ($4'5^{1}/_{8}''$) thick at the soffit.

During the 1944-45 air raids the bridge was hit on several occasions.

In addition to various injuries, the repair of which did not necessitate special arrangements being made, the first span from the left bank was cut through by a bomb, the point of impact being practically at 6 m. ($19'8^{1}/_{4}''$) from the top of the arch on the Epinay side, in the longitudinal sense, and about 1.50 m. ($4'11^{1}/_{16}''$) from the centre line of the structure, in the tranverse sense, and on the up-stream side *(Fig. 23).*

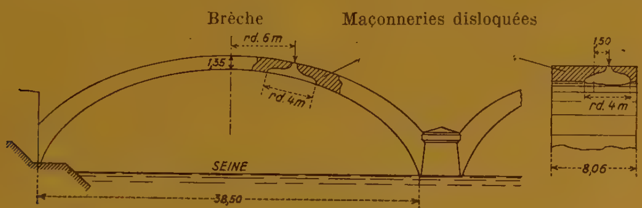


Fig. 23. — Epinay-sur-Seine viaduct.
Brèche = breach. — Maçonneries disloquées = dislodged masonry.

The opening made by the breach, very small at the top of the arch, widened out considerably towards the interior of it, where its diameter was about 4 m. ($13'1^{1}/_{2}''$).

If the space around the breach containing loosened parts is taken into consideration, it is seen that *the arch to all intents and purposes had lost about two thirds of its cross section on the up-stream side.* Local conditions stood in the way of building a temporary arched staging in the Seine for the purpose of the repair work, and therefore an arch piece above the arch itself, to which the necessary working staging could be suspended, had to be used.

This gave rise to two questions concerning in the one case the stability of the arch while the work was in progress, and in the other the method of effecting the actual repair of the breach.

Stability of the arch. The solution

involving using as a support an arch itself diminished in cross section by two thirds for the purpose of repairing it, being a risky one to adopt, I proposed before doing anything else to re-establish partially the static continuity alongside the breach by fitting the arch with three temporary lower segment pieces in reinforced concrete, put in compression, and exerting their effort against the full thickness of the arch on each side of the damaged area.

As *Fig. 24* shows these segment pieces, the radii of which varied from point to point, are placed at 1.75 m. (5′8 7/8″) centre to centre. They are about 22 m. (72′2 1/8″) long, 0.50 m. (1′7 11/16″) wide, 0.50 m. (1′7 11/16″) deep on the main open portion and 0.70 m. (2′3 1/2″) where they

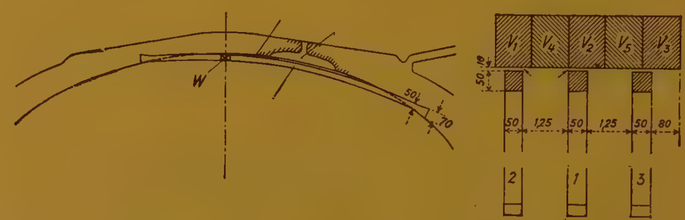


Fig. 24. — Epinay-sur-Seine viaduct.
Arrangement of the three provisional part segment pieces.

are embedded in the structure. They are 0.10 m. (3 15/16″) below the under face of the arch alongside the breach, to allow of placing boarding and securing pieces, and owing to their shape they penetrate bit by bit into the arch at their ends. Their reinforcing members are strengthened alongside the breach to take care of stresses acting where there is no support which can be brought about under the action of pre-compression. Anchorings A, flexible in the longitudinal sense, act against any tendency to lateral buckling.

The putting under load of each segmental piece, which is liable to suffer variations in the course of operations, was achieved by using a jack exerting a minimum force of 100 tonnes (98.420 Engl. tons) towards the top of the arch, this jack remaining locked until the end of the work. If the force to be exerted had been constant the use of expanding cement would have offered the simplest solution.

Repairing the breach. The three provisional segmental pieces having been made and put in place under load, one by one, the repair of the breach was effected in principle on the method applied at the Poix Viaduct, already described, that is to say by putting in five rings, each 1 m. (3′3 3/8″) wide, in the numerical order shown in *Fig. 24*.

The filler pieces, in concrete made with expanding cement, measured 0.60 m. to 0.70 m. (1′11 5/8″ to 2′3 1/2″) long and were separated by temporary joints about 10 mm. (25/64″) wide, the rings being on the other hand close against one another along their ordinary portion.

In addition to partial repair operations on damaged structures we may mention the complete rebuilding of *the arches of the Laroche Bridge, which carried five tracks on the Paris-Dijon line.*

The work comprises five 20 m. (65′ 7 3/8″) spans, with a rise of 1: 4.5 in non-reinforced concrete, measuring 1.22 m. (4′ 1/16″) thick at the top of the arch and 1.80 m. (5′10 7/8″) at the springings.

For reasons connected with the carrying out of the work each of these arches was formed *in two layers* measuring 0.50 m. and 0.72 m. (1′7[11]/[16]″ and 2′4[3]/[8]″) respectively at the soffit.

By agreement with the engineering staff of the French National Railways four successive operations were effected, as shown in *Fig. 25*.

First move : the first layer of each arch was poured, leaving a channel 1.20 m. (3′11[1]/[4]″) long in the top to take the first expanding filler piece.

Second move : the filler piece E_1 was

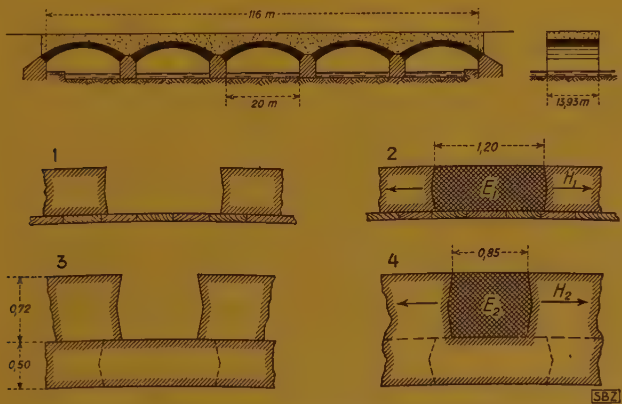


Fig. 25. — Laroche viaduct.

Fig. 26. — Laroche viaduct. Boxing for the filler piece E 1.

then made, on the usual process. This first filler was arranged to give an expansion of about 2.5 mm. ($^{25}/_{256}''$).

Third move : the first layer of each arch being finished, the second was poured over it, leaving again a channel, in this case 0.85 m. ($2'9^1/_2''$) long, to take the second expanding filler.

Fourth move : the second filler E_2 in each arch was made.

c) *Repair of damaged reinforced concrete structures.*

The so-called « Moscow » double track bridge near Montereau offers a striking example of a damaged reinforced concrete structure, comprising four 26 m. ($85'3^5/_8''$) spans, in continuous girder form, of varying height, restored with the aid of expanding cement.

When the Germans retreated in 1944, they endeavoured to destroy the bridge by placing torpedo bombs on the upper face of the superstructure.

Fig. 27. — Laroche viaduct. Filler piece E 1 concreted in place.

The pressure exerted by the upper filler pieces E_2 was arranged to just about equal 3/10ths. of that of the lower ones E_1, or 0.7 mm. ($^7/_{256}''$).

All the filler pieces were given 600 kgr. (1 323 lbs.) of expanding cement for each cubic metre used.

Figs. 26, 27, 28 and 29 show various stages of this work (1) which was visited by a number of foreign personalities.

(1) The test made on the Laroche Bridge on July 7th, 1947, showed an elastic versine of 0.4 mm. ($^1/_{64}''$) on the passage of the test train. See for details the French journal « Travaux » June 1947.

Figs. 30 and 31 show better than any description what the state of the structure was when its repair was entrusted to us.

The gaps having been cleared and trimmed and replacement reinforcements having been put in position between those rendered useless *(Fig. 32)*, the thing to do was to *restore the condition of mechanical stress formerly existing in the parts needing repair.*

Fig. 28 and 29. — Laroche viaduct.
Detail of the arrangement for measuring deformations.

If we had been satisfied to make the missing parts out of ordinary concrete their contraction tending to break the contact with the old concrete would have rendered the repair work partially ineffective. Their function would not have been fulfilled in fact save under loads of a relatively high value, that is to say when the elastic and plastic

Fig. 30. — Moscow bridge near Montereau.
State of the structure before the repair work.

Fig. 31. — Moscow bridge.
Destroyed main reinforcements.

shrinkages had exceeded the intensity of the contraction itself.

Therefore, wherever possible, we replaced the missing parts in strongly expanding cement, which its dynamic thrust put into compression in every direction, thus re-establishing at least to a partial extent the state of stress previously existing.

The Moscow bridge after being put into service again underwent conclusive tests, and to-day bears no apparent trace of the damage it received.

and against the mass of the concrete itself on the other.

As regards the armourings, our present quality of cement does not allow as yet of our obtaining a tractive load on the steel comparable in intensity with that which can be got by mechanical pre-stressing. We are at present continuing our researches with a view to improving this action, as much by the quality of the binding material as by putting concretes into actual use.

Fig. 33 represents the results obtained

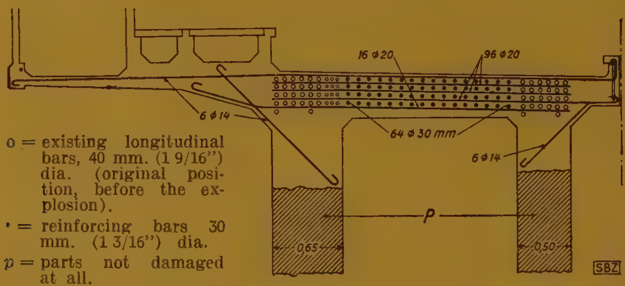


Fig. 32. — Moscow bridge.

d) Various applications of expanding cements.

The dynamic energy of expanding cements is brought into operation by anything which opposes their tendency to increase in size, whatever it be.

This effect is generally produced by metal armouring, either external or encased, or by abutting against masonry or earth works.

It then results *automatically* that :

— in the case of armourings there is a putting under tensile load of the steel parts and a correlative compression of the concrete, which is notably a function of the way the material is arranged and the percentage of metal involved;

— in the case of earthworks or masonry there is a compressive effort exerted against them on the one hand

with prisms of expanding concrete, having 550 kgr. (1 212 lbs.) of cement per cubic metre produced, reinforced respectively by 1, 2, 3 and 4 layers of hard steel having an elastic limit of over 100 kgr. per sq. mm. (63.4849 Engl. tons per sq. inch) or 10 000 kgr. per sq. cm.

As to the other applications, I limit myself to mentioning a few among them, in order not to lengthen my paper unduly :

Dams :

When compensating for contraction, the expanding cements will exercise a check upon the phenomena of cracking and splitting and unwished for internal stresses which at times attain to a relatively considerable intensity.

In the *arched type of dam* expanding vertical filler pieces or voussoirs will

exert a favourable pre-stress in a circumferential direction.

In the *weight loaded type,* the making of the joints will be simplified and rendered more efficacious.

Moulded piles in the ground, foundation and tunnel components, etc. :

The expansion, particularly at the enlarged foot of a pile *(Fig. 34)* exercises forced downwards. It is only possible, however, to construct in expansive cements certain components which act as jacks, as we saw in the case of arches. We are making experiments at the moment with a new process applicable to foundations of relatively large section.

For *tunnels and headings* of all kinds, expanding cements can be very well used, on the one hand for the keying of

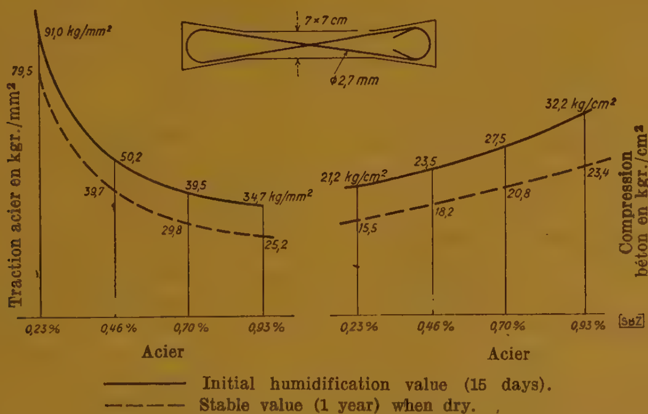


Fig. 33. — Results obtained with test prisms in reinforced concrete.

Explanation of French terms:

Traction acier en kgr./mm² = tension on steel in kgr. per sq. mm. — Compression béton... = compression on the concrete...

a distinctly favourable effect on the friction against the ground and in certain localities on the local firmness round about it.

We may note that in certain water-bearing soils humidification is obtained automatically.

We repeat, however, that our existing qualities of cement give no guarantee of immunity against the action of sea water, or water containing sulphates of calcium.

In the case of *foundations,* whether in *solid blocks or of hollow form,* the expansive effort exerted against the ground forms at all times a favourable feature, from the point of view of resistance to any tendency to become

arches, on the other for applying grouting between them and the ground that is being traversed. Some trials are in progress in connection with an important tunnel in North Africa.

Fig. 34. — Bulb foot of pile made in expanding concrete.

Packing, grouting and rendering firm

the headings in mines offer particularly interesting applications.

Conduits and pipe lines :

In applying reinforcement or armouring to conduits and piping, both longitudinally and radially, to resist the tendency to expand, *we set up automatically a state of compression in the concrete in two senses,* less intense certainly under present conditions, than is obtainable by mechanical pre-stressing, but which nevertheless shows itself to be sufficient in certain cases.

An *outer casing of fibro-cement,* used as a boxing in *(Fig. 35)* will produce in like manner *without any armouring* this double stress compressive action.

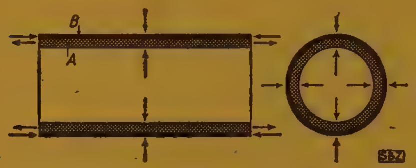


Fig. 35. — Tube in expanding concrete, outer sheathing in fibro-cement.

The superiority of expanding cements from the point of view of *impermeability* will always also be an important factor to bear in mind.

Coating and aprons :

The first trials made by M. FAURY appear to be giving satisfactory *results;* I am waiting to watch their behaviour over a length of time before expressing a definite opinion.

Running surfaces of roads and aeroplane runways :

The contraction accompanying the hardening of concrete, much more than temperature variations, leads the builders of roads or runways having concrete surfaces to provide at intervals some arrangement for ensuring continuity of surface, or *joints* intended to avoid cracks caused by tractive forces.

Such joints, like those in railway lines, offer many disadvantages, well known of course, quite as much in connection with local wear as with the wear and tear of vehicles or the comfort of passengers.

In the vicinity of a joint especially the local unit rate of pressure on the ground when a single axle passes may reach in certain cases four times that obtaining on the ordinary parts of the surface, which easily explains how worn conditions get set up at such points *(Fig. 36).*

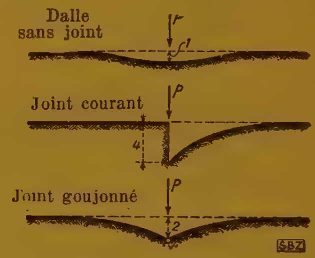


Fig. 36. — Giving way of surfacing under the passing of a single axle.

Explanation of French terms:

Dalle sans joint = paving or flagstone without any joint. — Joint courant = ordinary end-on joint. — Joint goujonné = pinned or articulated joint.

The steel bolt fastenings used to maintain the ends of two consecutive paving stones at the same level generally form only a semi-articulated joint, so that the pressure on the ground in the vicinity still amounts to about *double* that of the load met with elsewhere.

To avoid having to use special kinds of joint, it was clearly of advantage to investigate the possibility if not of getting rid of joints entirely, at least of effecting a noteworthy reduction in their number.

Let me remind you that certain railway companies have already obtained interesting results in this sense as regards their rails.

Under the action of heat these tend to

put themselves in a state of resistant compression, if their tendency to buckling is sufficiently held in check, both vertically and horizontally.

With concrete surfacings, the problem is reduced to investigating buckling, in the vertical direction only, of paving or flagstones, resting on a stable foundation and loaded with their own weight which exerts a compensating action of a very important kind in that direction. In addition one has to take into account the fact that under the action of the sun, differences of temperature of the order of 30 to 35° C. can occur between the upper and lower faces of the paving.

I have therefore begun a programme of researches in France covering the possibility of constructing roadways and aeroplane runways in concrete, if not without any joints at least with a very small number, making use especially to a greater or lesser degree of the expansive properties of cements.

This programme, subsidised by the French Ministry of Public Works, comprises various series of tests made in the first place with wooden or concrete models, with electric heating of the upper surface reproducing the effects of the sun, and then with actual works.

These operations are at present being carried out and I shall shortly make known the results in a lecture to be given in Paris.

The French National Railways are following these experiments, which interest them from the point of view of buckling of the rails, and following that, the construction of a jointless track.

Mixed applications :

There are in practice numerous cases where *expanding cements will find application in conjunction with mechanical pre-stressing.*

In the case of *high pressure pipe lines* for example, the longitudinal pre-stressing needed is distinctly less than the diametral pre-stressing which is called for.

It is possible therefore to make moulded elements in expanding concretes, a few longitudinal bars sufficing to keep the material in pre-compression in that direction. All that is then required to get the double effect is to arrange external armouring put under tractive load mechanically by ordinary processes. The mechanical longitudinal pre-stressing is thus done away with. Trials are at present being carried out on this subject in France and North Africa.

In the case of *floor or bridge girders* expanding concrete can be used to obtain a transverse compression, thanks to the hooping and binding which oppose any expansion, while the longitudinal bars are put under stress mechanically.

It would be possible to cite still further examples of the same kind, but time does not permit of it.

Calculating the action of the expansion.

Let us consider the simplest elementary case, that is where we have two prisms of small thickness bound solidly together at the ends and obliged in consequence to retain equal lengths when one of them tends to expand under the action of some force of that nature *(Fig. 37)*.

Fig. 37.

Let us indicate by :

Δ_O : the elongation which the expanding prism *A* would manifest if it were freed from all connection with the ordinary one *B*;

Δ_R : the actual elongation which the

two prisms A and B will manifest together;

Ω_A and Ω_B : respective cross sections of the prisms;

E_B : the coefficient of elasticity of the concrete in prism B;

H : the connecting thrust set up by the expansion between the two elements;

R : the compression of prism A under the action of this thrust H.

We have :

$$\Delta_R = \frac{H}{\Omega_B \cdot E_B} \text{ and } R = \frac{H}{\Omega_A}$$

from which we get :

$$\frac{\Delta_R}{R} = \frac{\Omega_A}{\Omega_B \cdot E_B}$$

which constitutes the characteristic of the system.

which the representative curve forms the *expansive dynamic curve*, which has to be determined experimentally for each kind of concrete, easily done by means of the Faury apparatus.

Let us assume this curve to be known for a given class of concrete *(Fig. 38)*, the elongation Δ_R being shown by ordinates and the corresponding pressure R as abscissae.

In tracing the secant O.N., of which the angle made with the horizontal has as its tangent the relation $\frac{\Delta_R}{R}$, we get the *actual values* of Δ_R and R *for the concrete in question.*

If it is a question of obtaining *(Fig. 39)* for one or other of these terms a known numerical value Δ_{RO} or R_O, use is made of a group of curves each of which applies to a particular proportion of concrete composition, which enables

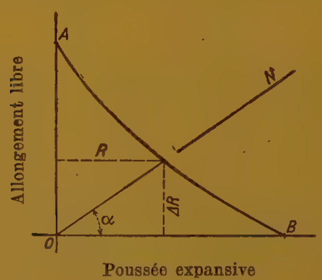


Fig. 38. — Expansive dynamic curve.

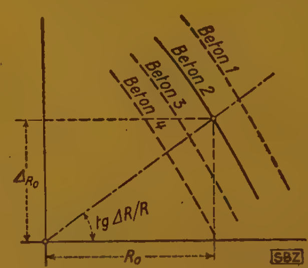


Fig. 39. — Expansive dynamic curves for various types of concrete.

Allongement libre = free elongation. — Poussée expansive = expansive thrust.

If the expanding prism A functioned elastically the relation $\frac{\Delta_R}{R}$ would be a constant equal to $\frac{1}{E_A}$, E_A then being the coefficient of elasticity of prism A.

But in consequence of the plastic deformations occurring in the concrete in the course of its expansion under restraint, this relation is a variable of

one to select the type of concrete to use. In our figure the expansive dynamic curves are shown referring to four different kinds of concrete, numbered 1 to 4.

It goes without saying that when the two prisms A and B which we have had in mind have a non-negligible thickness, when calculating the effect of the expansion we must take into account their

deformation through bending. If they are bound solidly together throughout their length, their radii of curvature must in addition be equal.

But whatever the case may be, we always are brought back to determining the characteristic $\Delta_R : R$ of the system under consideration.

Conclusions.

In a general way, along with very valuable qualities, all cements suffer from two principal defects, which are :

— *their low resistance to tractive loads;*

— *their contraction when exposed to the air.*

The first of these has been somewhat modified in the case of high quality cements produced in recent years, but if their resistance to tractive loads has gone up in absolute values, it has done so in a degree distinctly inferior to that of the resistance to compression, so that the *fragility* of cements has thereby increased, reducing appreciably the interest awakened by the progress achieved from the point of view of practical application.

As to the contraction brought about by hardening in air, the creator of so many unwished for stresses and cracks, its intensity has been reduced somewhat by various processes without however causing them to disappear entirely.

Expanding cements do not indeed get rid of it, but they *compensate for it,* in giving rise to an initial expansion equal to or greater than the intensity of contraction occurring with the passage of time.

If I was, at least so far as I am aware, the first to consider the possibility of *achieving automatically the three-fold effect of action and re-action in concrete by making use of the expansive power of special cements,* my idea would have remained sterile if eminent chemists, to whom I must pay a tribute, were not interested in it and had not contrived to make such cements.

To obtain a cement which expands while hardening was something already known, but it formed at that time more often than not only a mere accidental circumstance in the course of manufacture.

Like fire which is so destructive when it has free rein, but so beneficial when kept under control, the expanding power of cement could only be turned to account after having been rendered both *amenable to regulation* and *stable.* Moreover this stability could only be vouched for after several years of observation. This is why I had to proceed with numerous experiments and tests before making practical applications of my ideas, although my first communication to the International Bridge and Girderwork Congress, which dates from 1936, is already over 10 years old.

By reason of their qualities of impermeability and compact structure, favourable to the preservation of the reinforcements and resisting the action of external agencies, expanding cements seem called upon to replace other kinds, little by little, in many applications. The *slightly expansive mixtures,* intended above all to compensate for contraction, will be used particularly in ordinary classes of work.

The *strongly expansive types,* on the other hand, will be kept for special cases which make use, by holding it under restraint, of the powers of expansion possessed by them.

But the idea is only at the beginning of its practical applications, and we shall have to wait to see it develope, notably in the coming years.

Alongside the first expanding cements which have opened the way, others will be produced in due course. Wherever

they come from, I shall be delighted to see them make progress.

* * *

Let us in concluding cast a glance over the whole question in order to try and fix the place in the history of engineering construction, and more especially in that of reinforced concrete, of the tendencies operating to-day.

Is it possible to affirm that our modern conceptions relative to the prestressing of concrete, whether obtained by mechanical means or by the use of expanding cements, represent at least the commencement of what will become *definitely* the forms to be taken by reinforced concrete in the future ?

Whatever may be the opinion of certain experts on this matter, for which indeed there is much to be said, I personally do not feel sure of this myself.

As I have said elsewhere, my belief is that these ideas will form a stage in the history of reinforced concrete, one which may be brilliant in the results achieved, but still an intermediate stage.

The concrete we are acquainted with is not high quality material like steel. Although an artificial product it is a poor material, which its varying powers of resisting certain stresses and strains and its fragility oblige us to use to a limited extent only, unless it is supported by other elements.

The reinforcements which formed the first stage in the development of reinforced concrete have allowed us to use the material for more than half a century in a wide and varied field. However legitimate our desire to replace it by something else and to adopt new methods we must admit that such of its applications as have been intelligently carried out from all points of view have justified the hopes founded on them.

The experience gained in the course of time has not, in fact, confirmed certain excessive fears regarding the effects of splitting and cracking and dynamic effects. Therefore in my opinion, *the classic form of reinforced concrete, if need be improved, should survive and continue to be used still, concurrently with our new methods.*

These modern methods which have revived the conception put forward by DOEHRING, while amplifying and completing it, have freed reinforced concrete from the risk of cracking, while allowing us to use it more completely than before.

Time and experience alone will show what their exact place in the future is to be. We are too near to them ourselves to be able to judge definitely.

And what would be more particularly the scope of the economies that will be realised in this way, in the end? It is difficult to state them with exactness today. Indeed in bringing everything down to the present time, as is done on occasion, a time which is exceptional and abnormal, we risk creating a mental outlook which insists in attributing to the future the quite transitory difficulties of the present time.

* * *

However that may be, our old and our modern conceptions both can have no other object than to overcome the deficiencies of that incomplete material which is the concrete of today. We bind it round, bandage and bleed it like a sick organism.

Who knows, and this is how I take a glimpse at the future and the development of its history, but what our successors will not succeed in simply curing it of its infirmities.

When we shall have succeeded in making binding materials, — I do not say cements, — which while economic to use will be free from the defects of stone materials, the problem will no

doubt not be solved completely but a great step will have been made in that direction.

Swiss industry occupies incontestably an honoured place in the manufacture of cements, as much for the reliability as for the high qualities of its products.

It was with a Swiss make of cement indeed, the Holderbank, that I carried out in France my first experiments in the matter of rapid hardening.

But, Gentlemen, in spite of this privileged position, your work as cement manufacturers is far from being at an end. Your investigations will need to be intensified in the direction of research into the production of cements which, while less fragile, will nevertheless possess high qualities of rapid hardening and expansive energy without being handicapped by prohibitive selling prices.

Gentlemen, I pay tribute in anticipation to the Swiss chemist who, as I like to hope, will bring us the perfect cement of the future.

MONTHLY BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

(ENGLISH EDITION)

PUBLISHING and EDITORIAL OFFICES : 19, RUE DU BEAU-SITE, BRUSSELS

Yearly subscription for 1948 : { **Belgium . . . . 700 Belgian Francs**
Universal Postal Union . 800 Belgian Francs

Price of this single copy : 80 Belgian Francs. (not including postage)

Subscriptions and orders for single copies (January 1931 and later editions) to be addressed to the General Secretary, International Railway Congress Association, 19, rue du Beau-Site, Brussels (Belgium).

Orders for copies previous to January 1931 should be addressed to Messrs. Weissenbruch & Co. Ltd., Printers, 49, rue du Poinçon, Brussels.

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